Boosting BSM Higgs searches

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based on work with:

Graham Kribs, Tuhin Roy,
Michael Spannowsky

arXiv: **0912.4731, 1006.1656, 1012.2866**

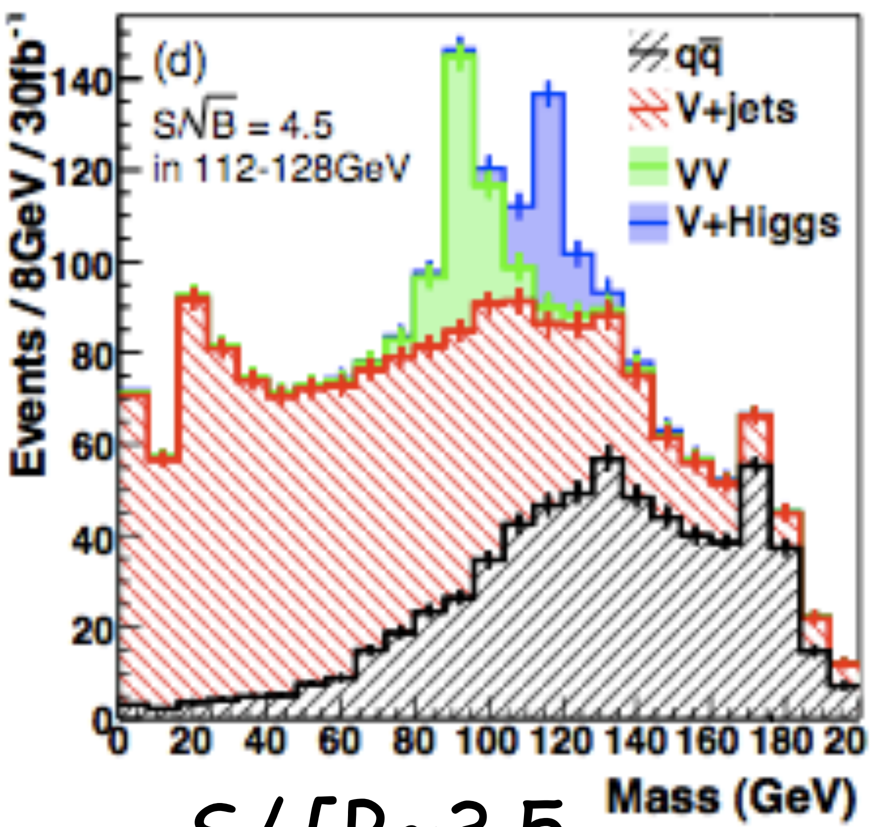
SUSY, August 29th, 2011

Fermilab

Introduction & Motivation

light Higgses (m_H < 130 GeV) are traditionally difficult to find

h -> $b\bar{b}$ decay mode revived for boosted Higgses via jet substructure (see **BDRS**, 0802.2470)



S/√B~3.5

In this talk:

... what about boosted Higgses from BSM?

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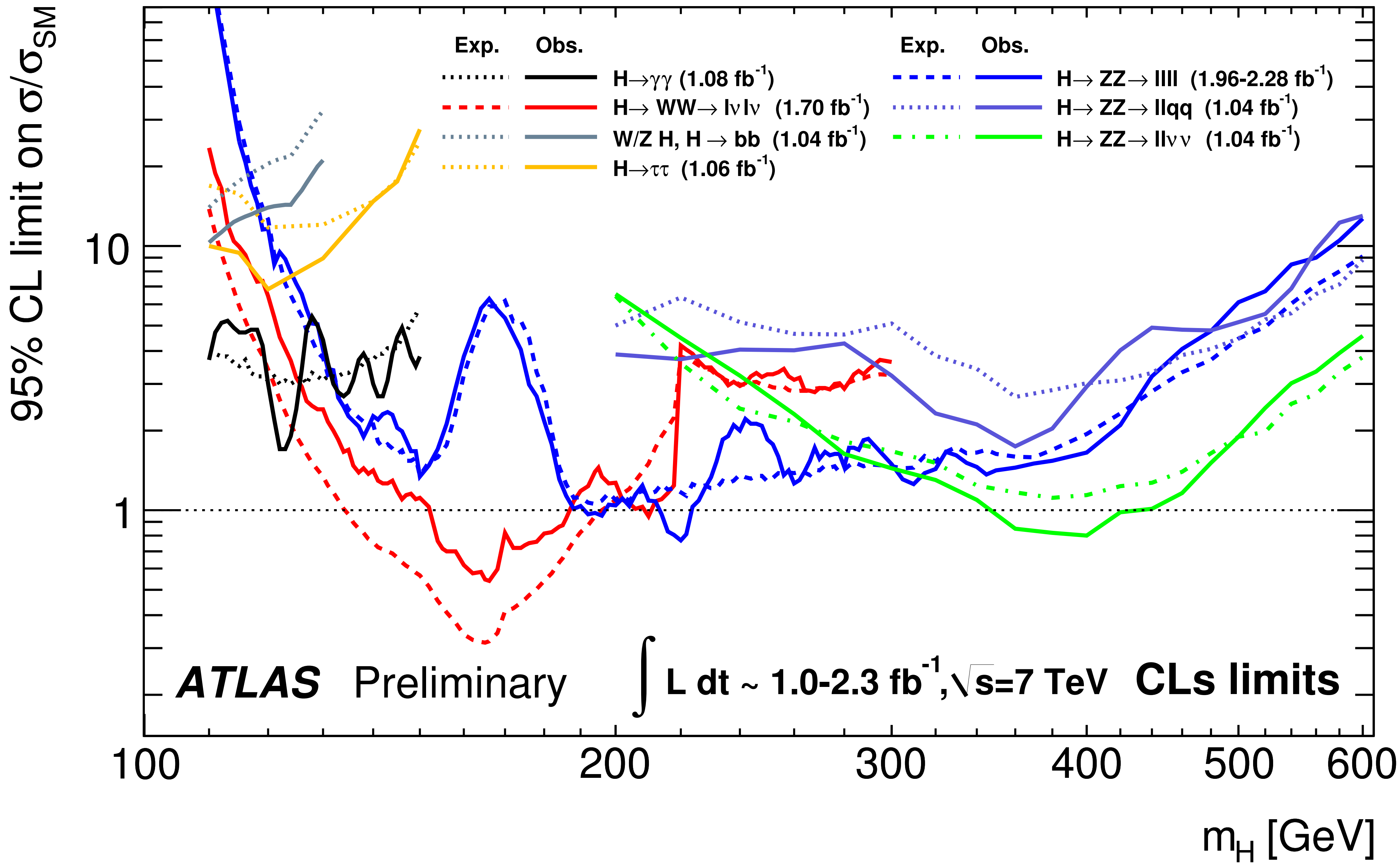

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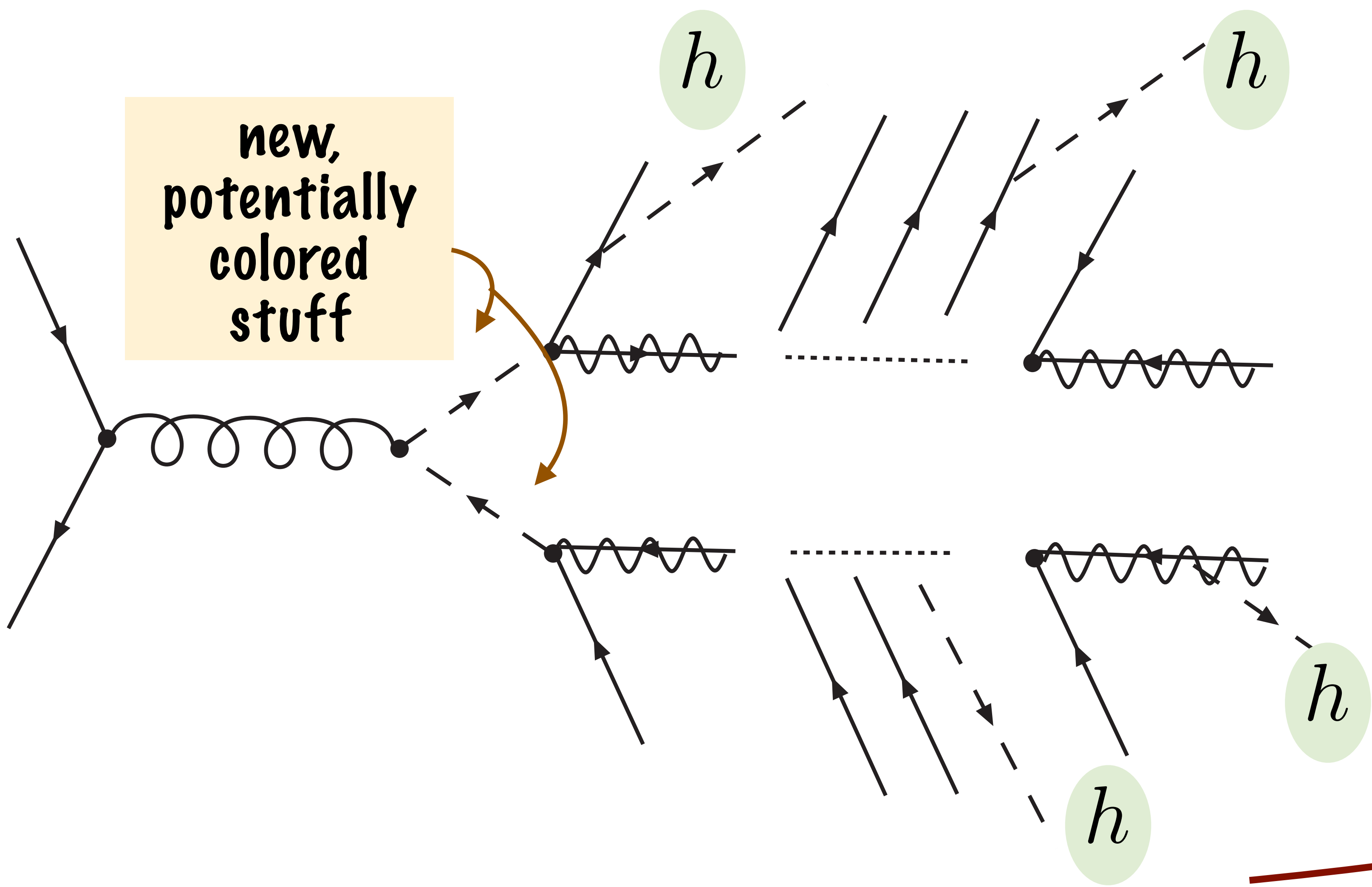
Higgs from BSM decays

BSM stuff often talks to the Higgs

$\therefore$ BSM particles can decay to Higgses



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while Higgs can be light

high fraction of boosted Higgses

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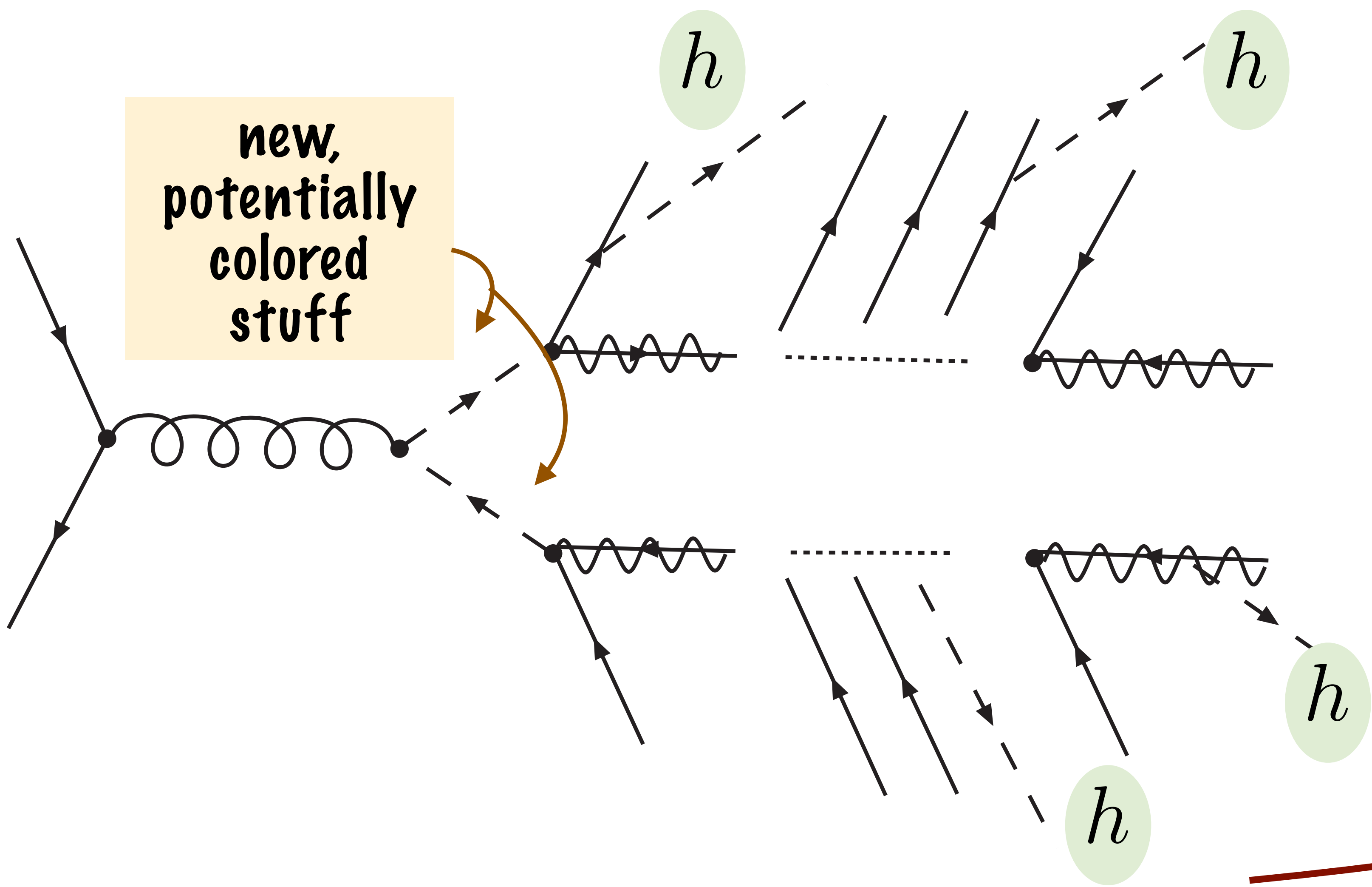

= a new source of Higgses

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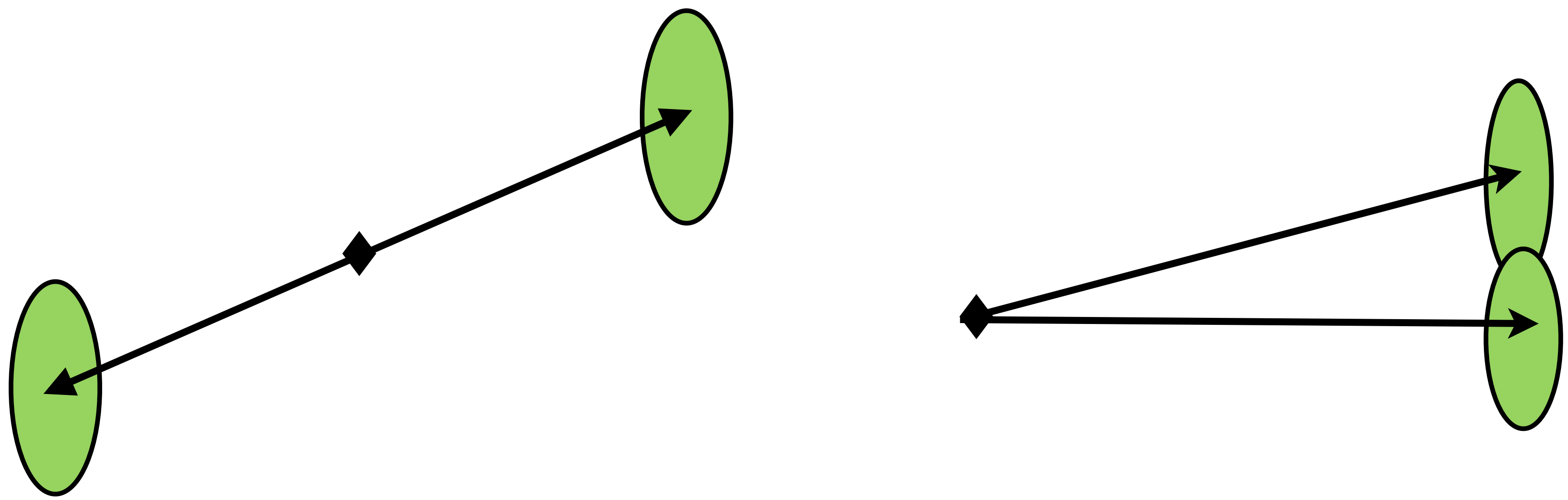
Boosted Higgses:

when a heavy particle (Higgs) is boosted, its decay remnants get closer together in the detector



both decay products (+ associated radiation) can be captured by taking a larger jet cone -- resulting in a single 'fat-jet'

$R_{jj} \sim 2\, m_R/p_{T,R} \sim 1.2$ for $m_H \sim 120$, $p_{T,H} \sim 200$ GeV

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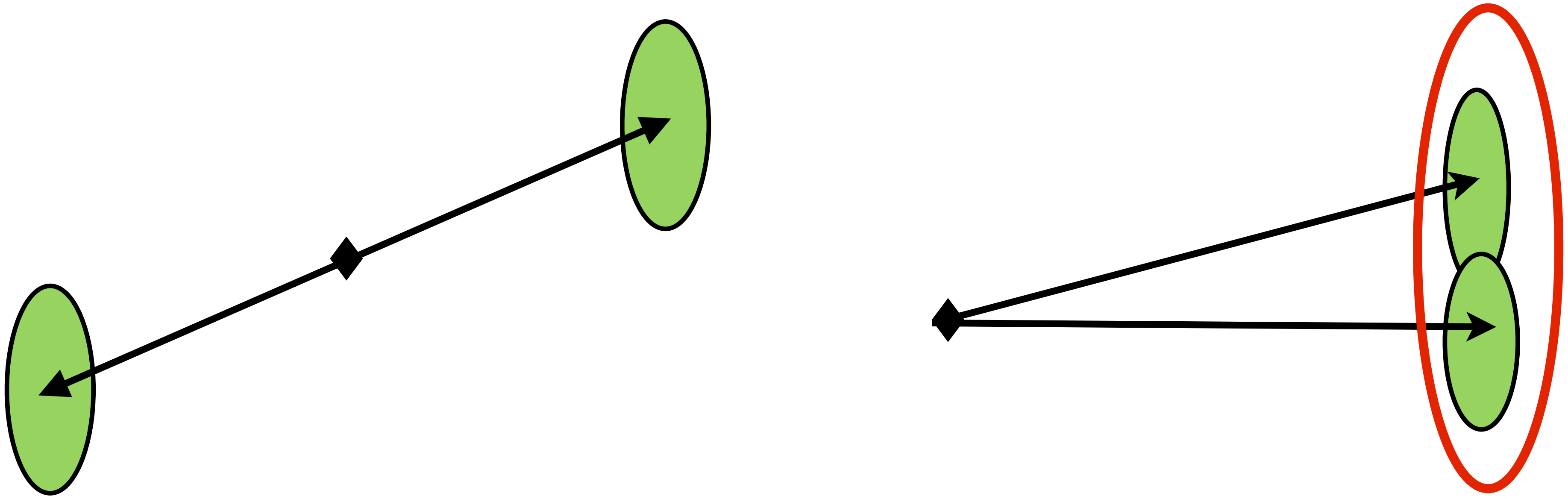

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Boosted Higgses:

(BDRS)

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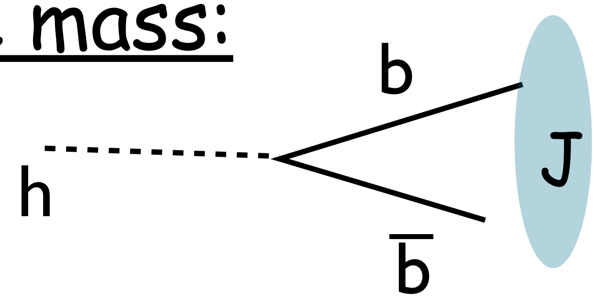

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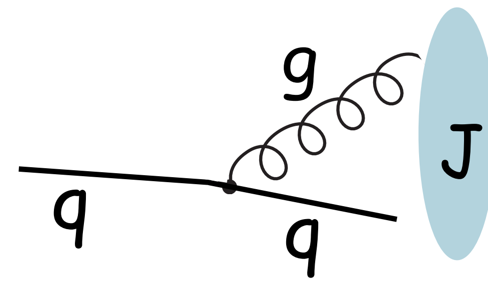
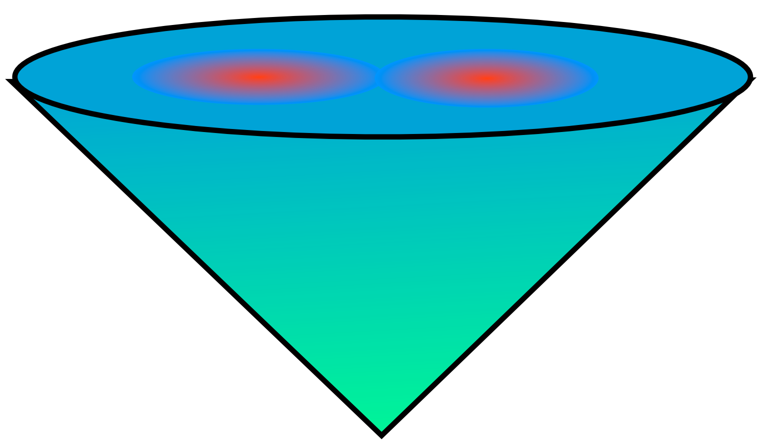
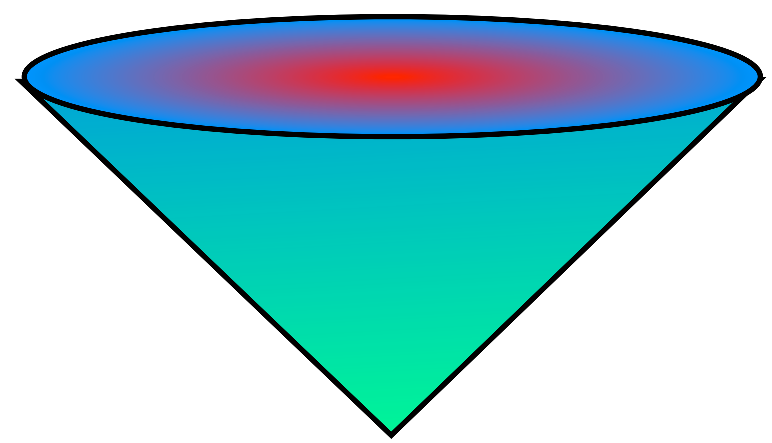


$m_J \sim p_T \, \Delta R_{gq}$
typically $\ll m_H$

2. distinct energy deposition pattern: multiple 'cores' of energy





3. no combinatorics:

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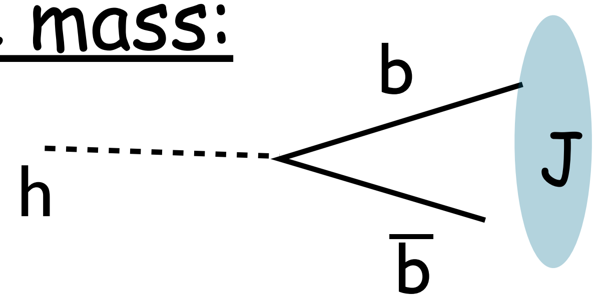

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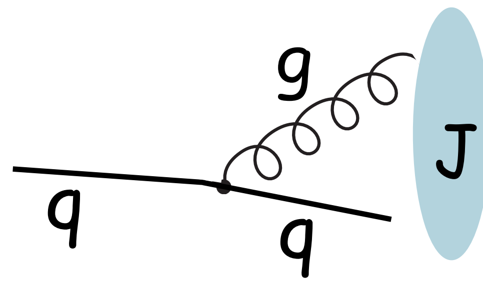

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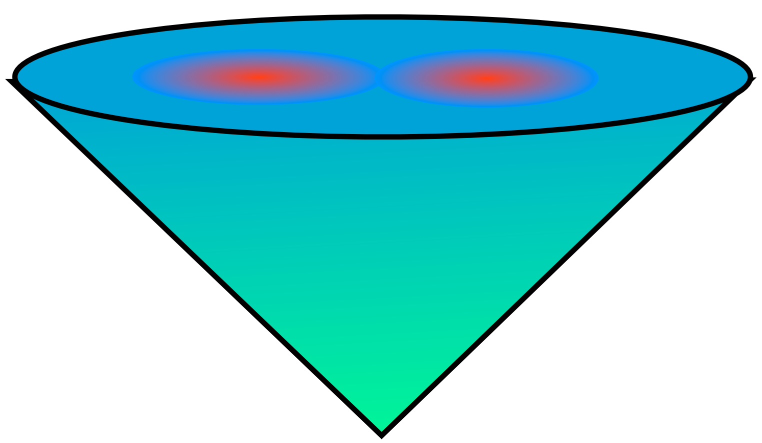

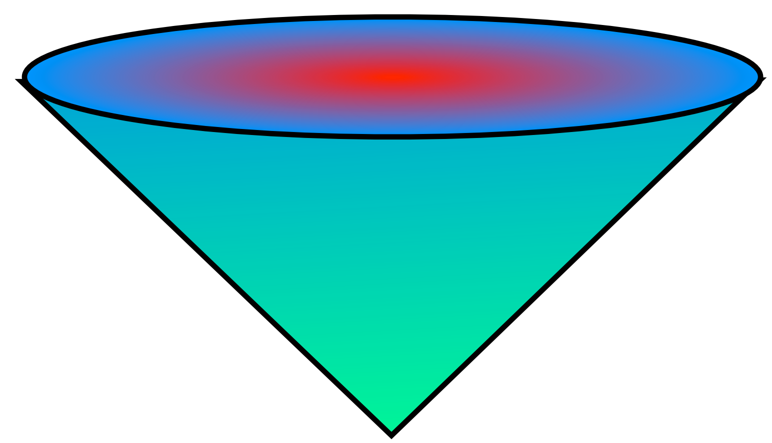

exploring the jet on smaller and smaller scales:

at some point, signal jet will fall apart into **~2 subjets with similar properties**.
QCD background is dominated by **asymmetric splitting**,
so it will rarely look like the signal..

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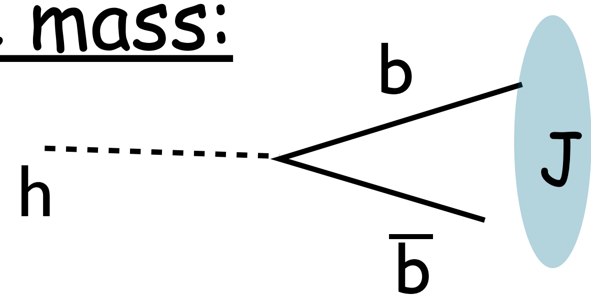

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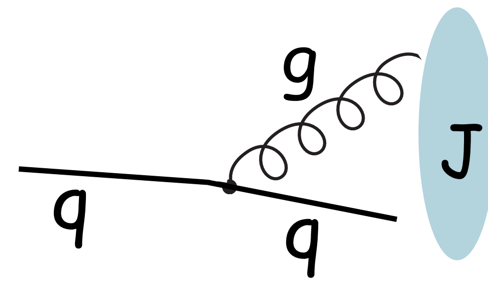

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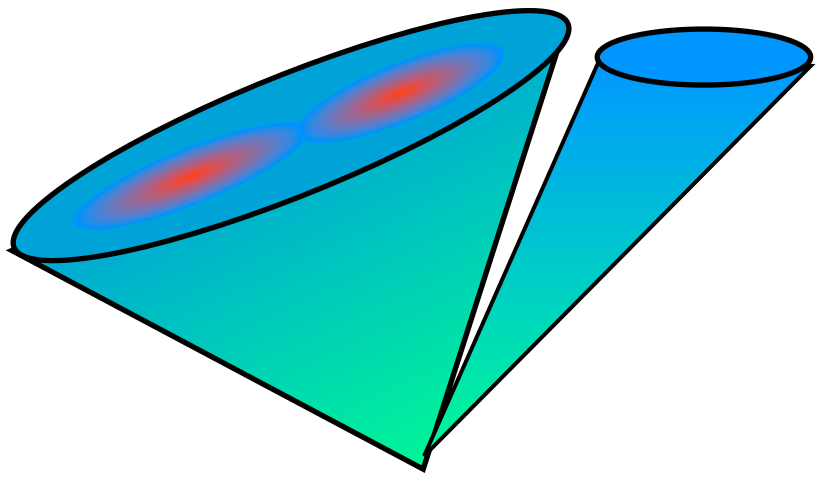

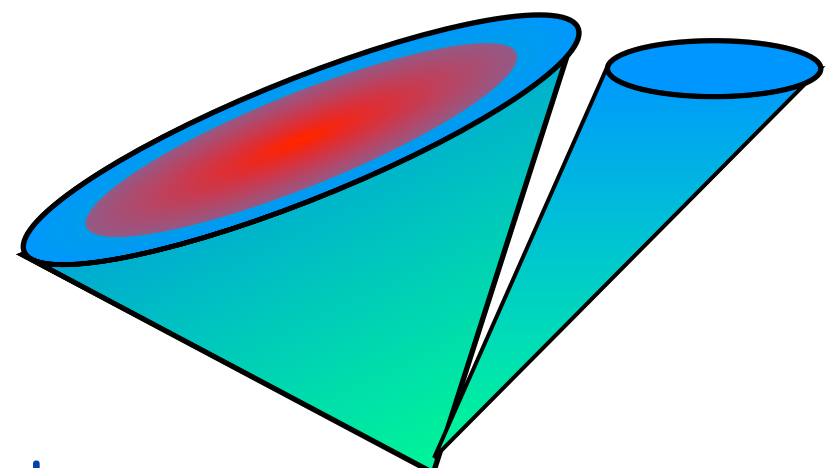

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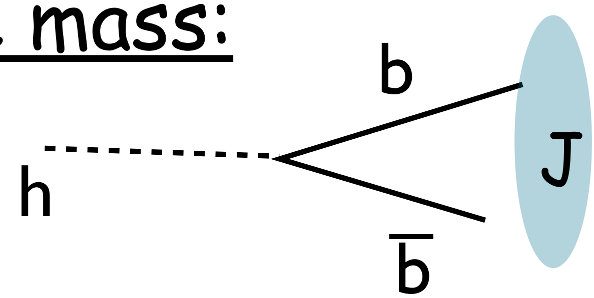

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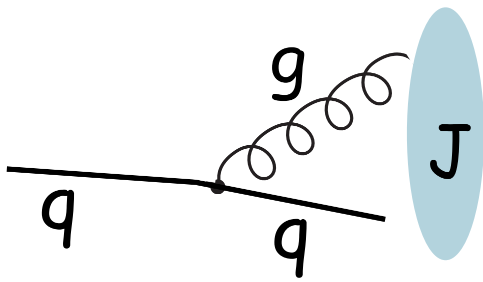

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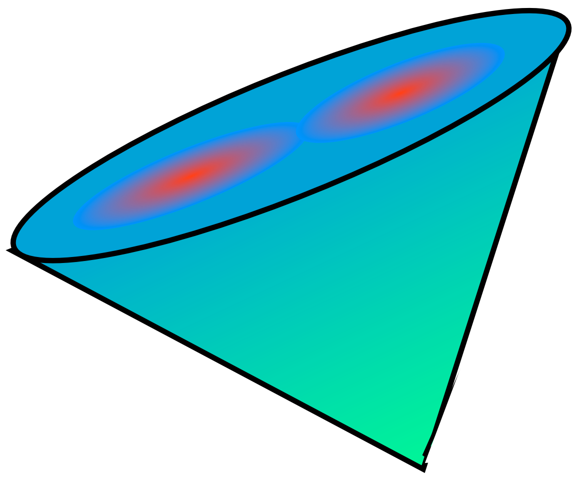

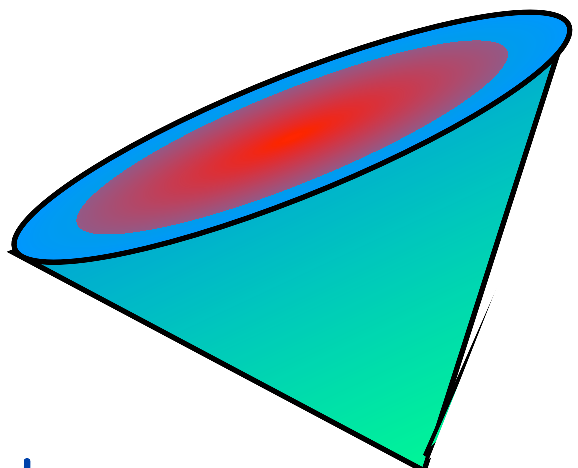

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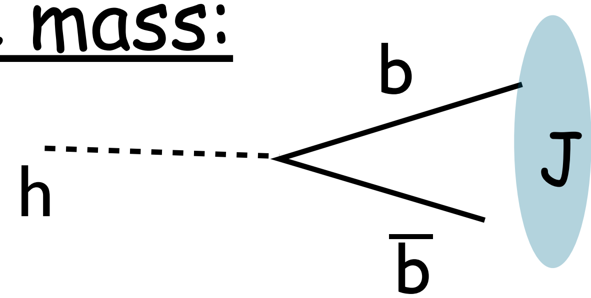

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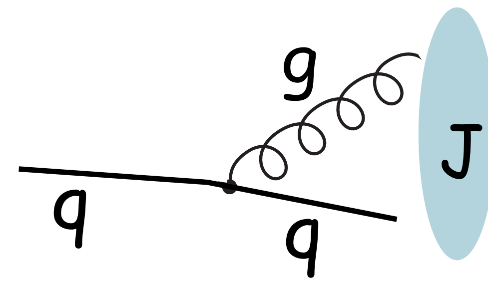

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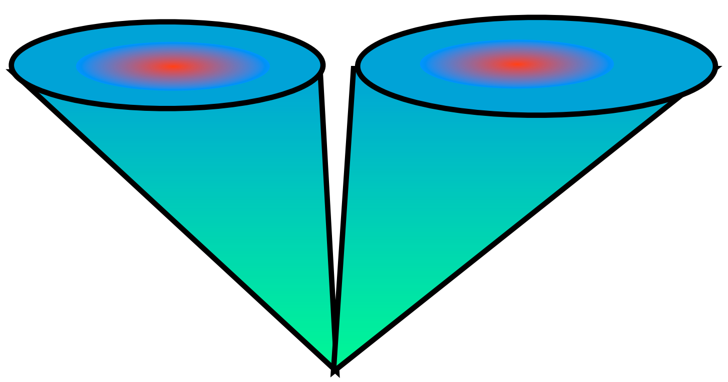

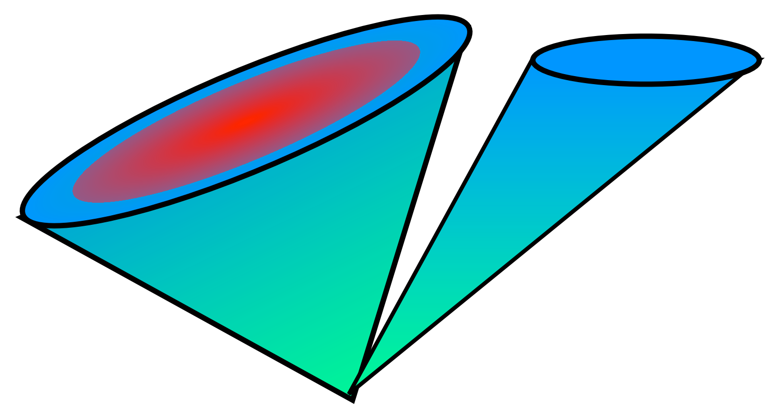

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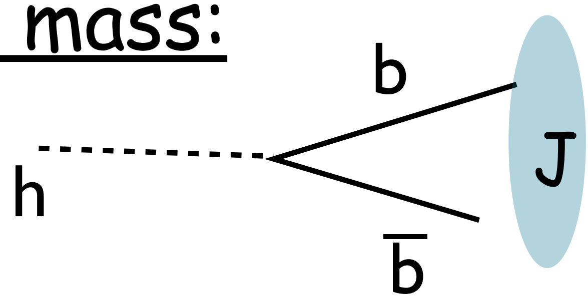

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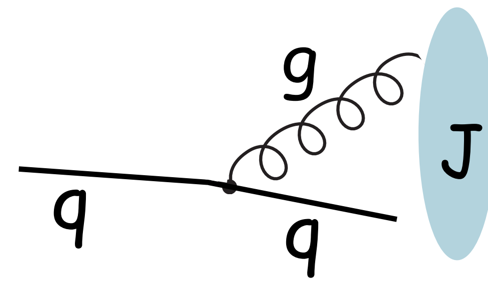

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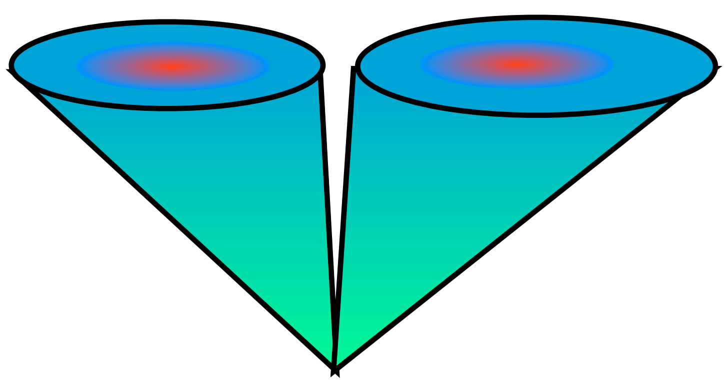

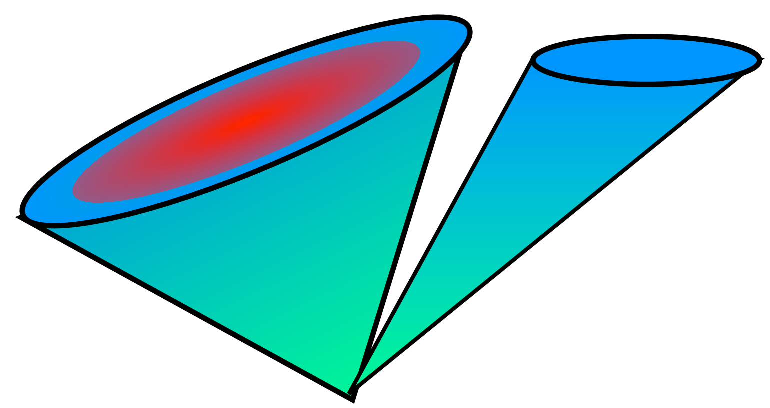

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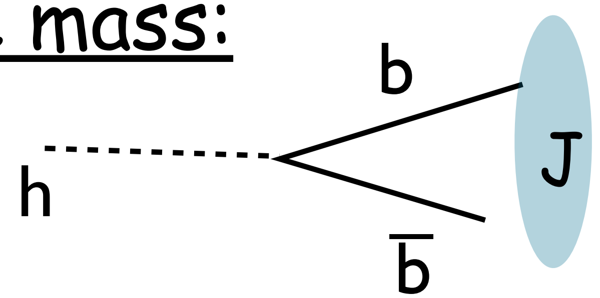

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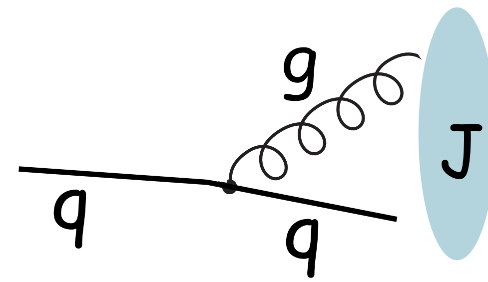

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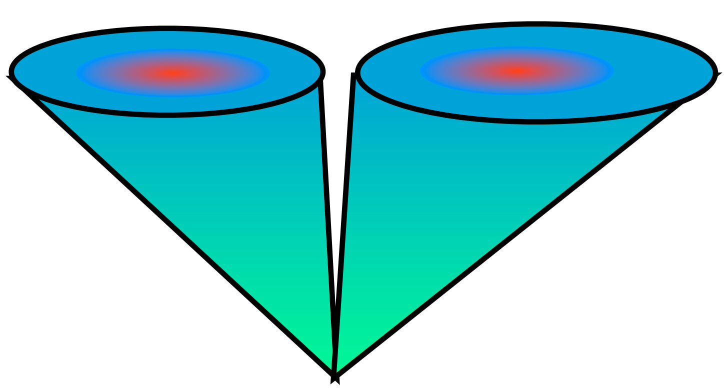

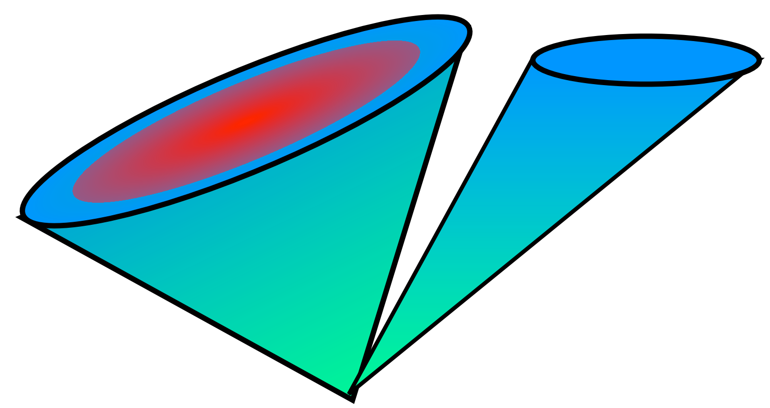

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3. no combinatorics: look for Higgses within **single 'fat'** jets passing these substructure criteria, **not** between all pairs of jets

Boosted Higgses:

boosted techniques, while powerful, are limited in the SM by the small fraction of events with sufficient boost/topology: ~2-5% for $W(l\nu)H(b\bar{b})$

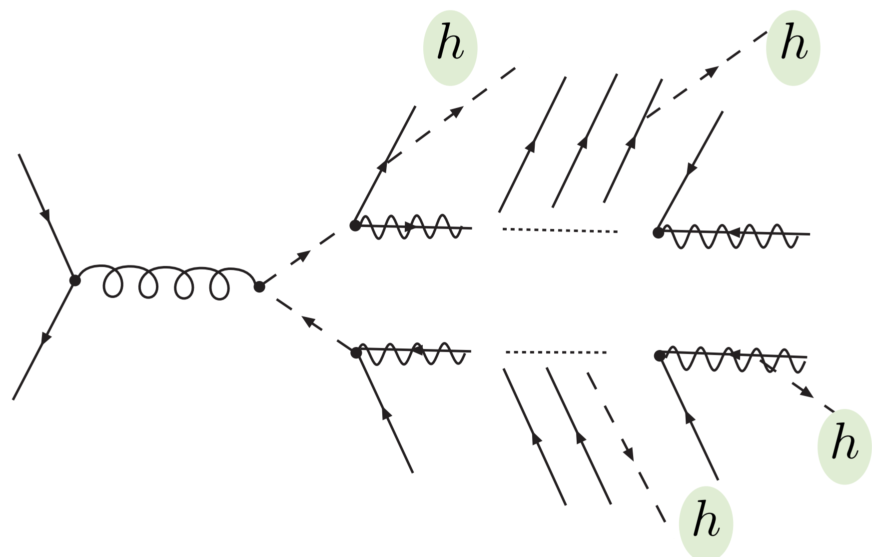
not the case for Higgses from BSM cascades!

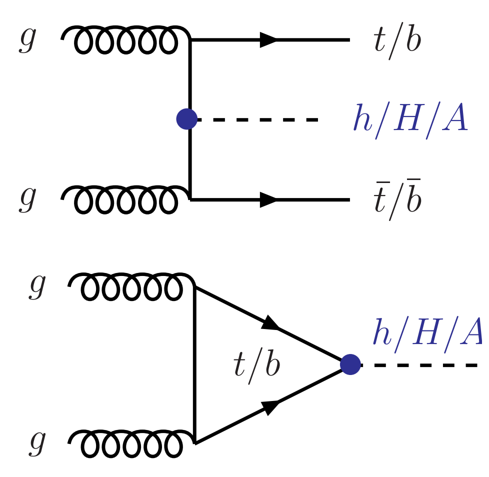
on to BSM

1.) Pick your favorite BSM model

- needs Higgs (the lighter, the better)
- needs stuff which interacts with Higgs

2.) Look in all BSM events, rather than just ~few channels





3.) Find 'fat' jets passing substructure criteria

4.) Plot m_J, look for bump

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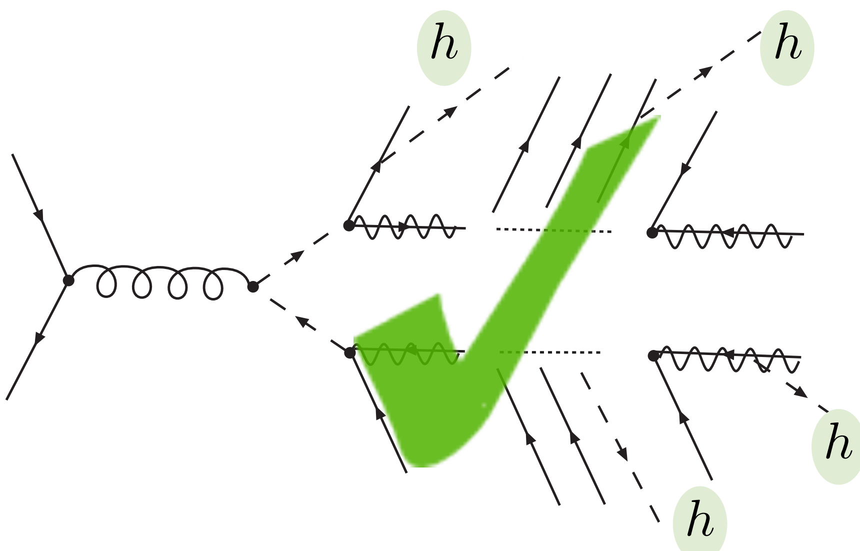

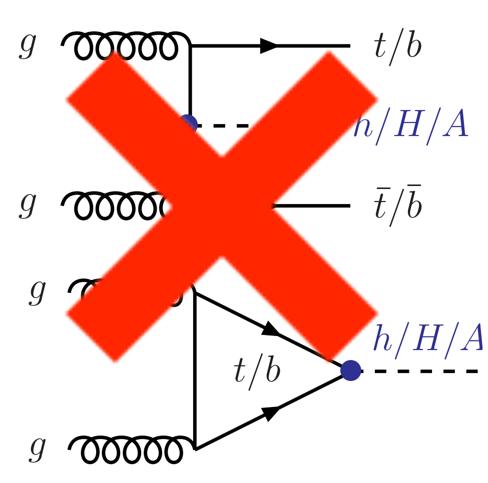

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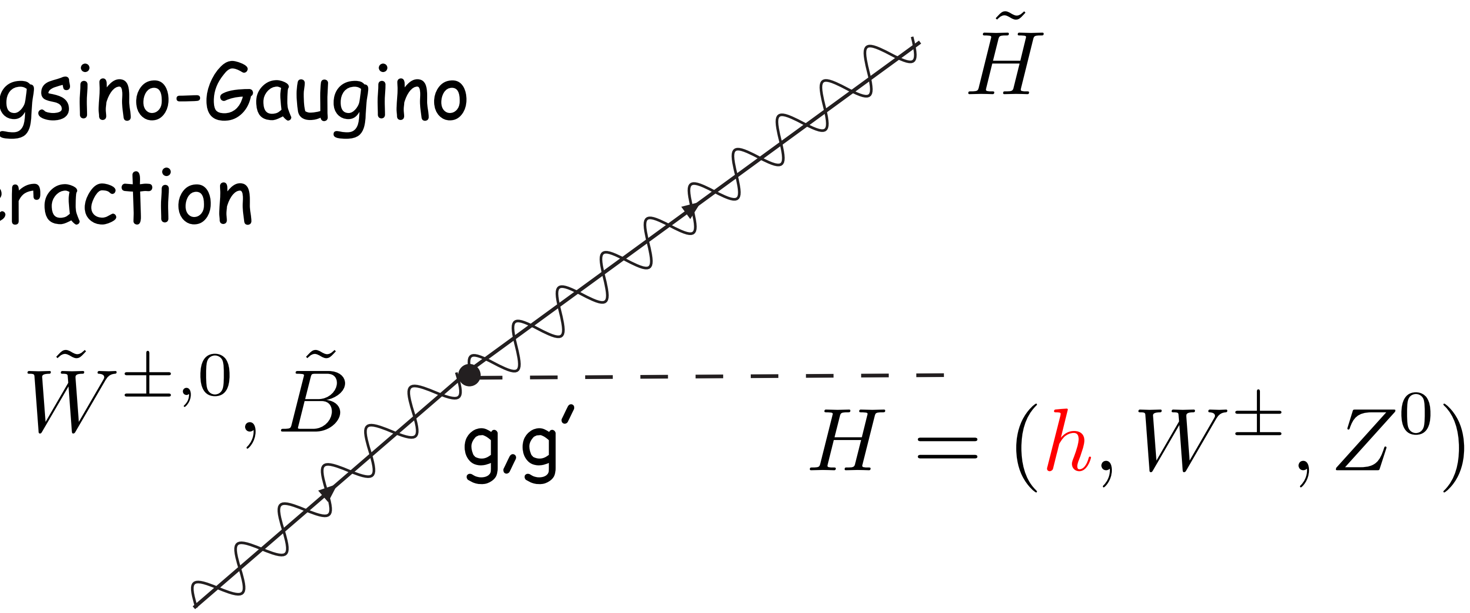
Boosted Higgs in the MSSM...

Higgs-Higgsino-Gaugino
interaction



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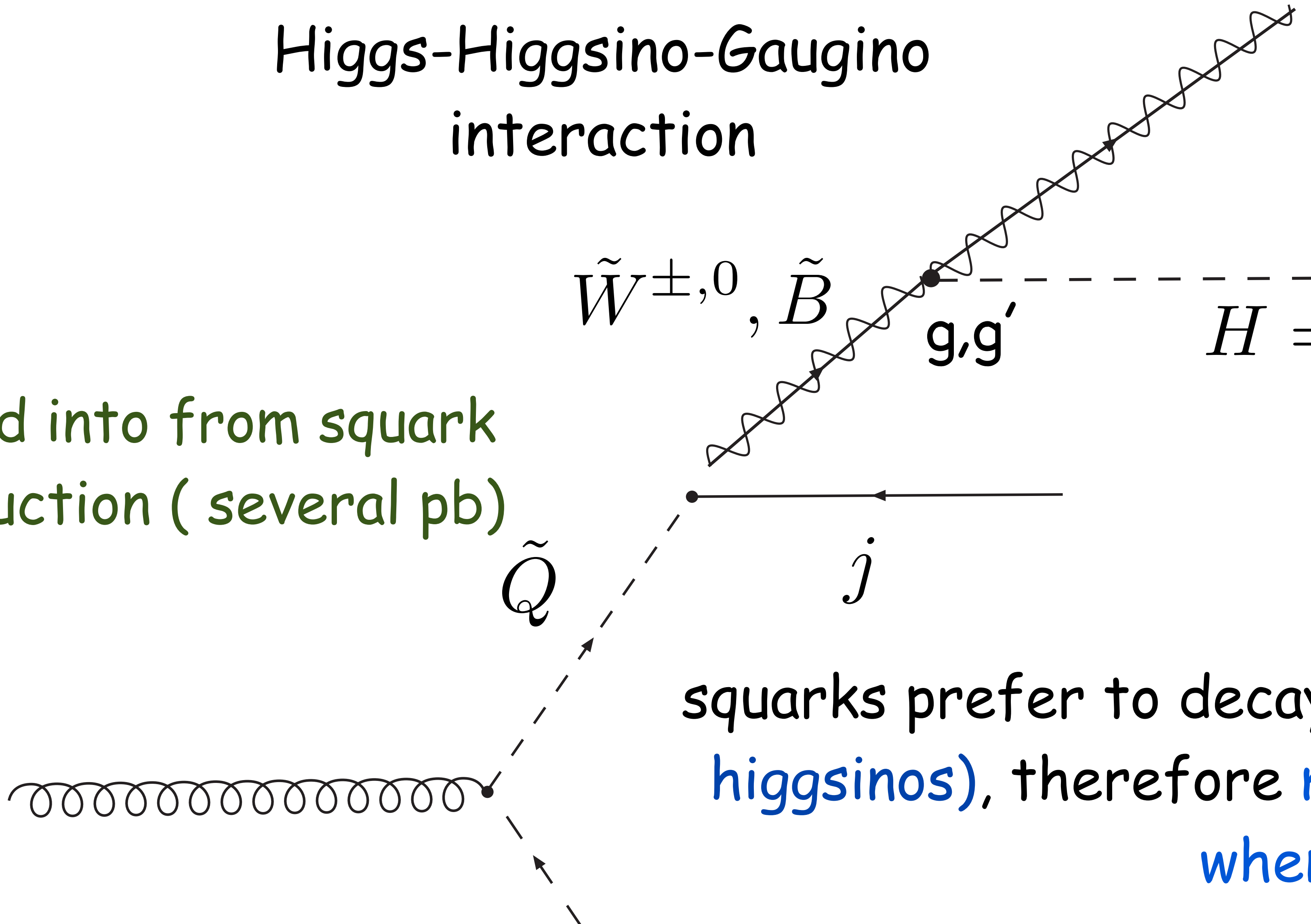
Higgs-Higgsino-Gaugino interaction

$\tilde{H}$ = LSP = $\not{E}_T$



$H = (h, W^{\pm}, Z^0)$

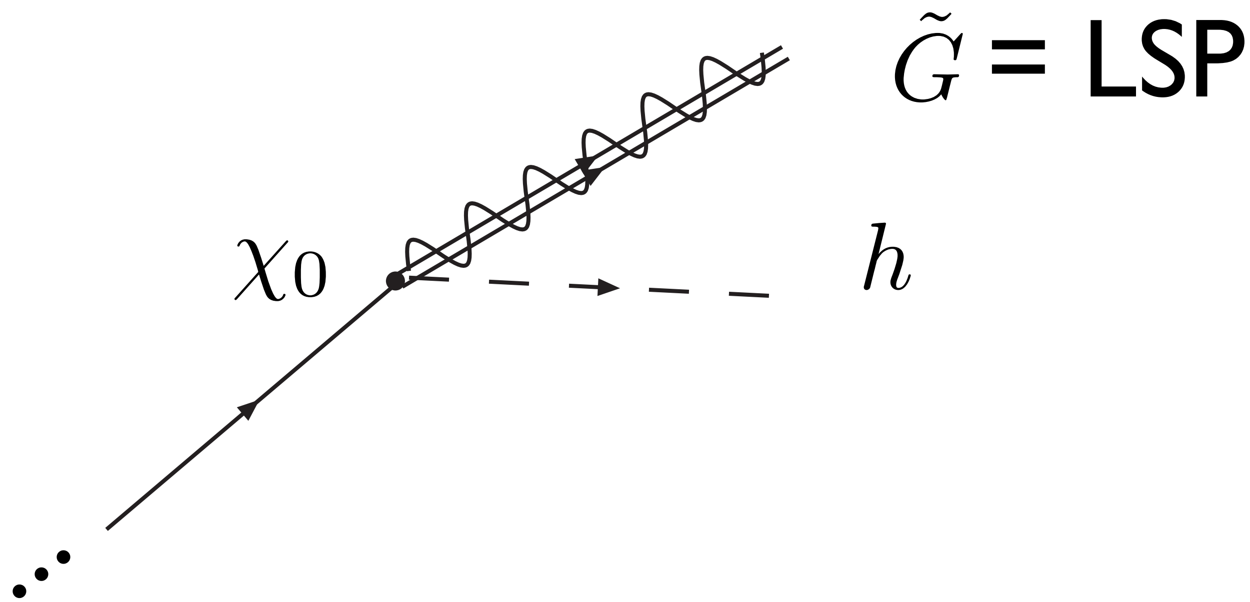
... fed into from squark production (several pb)

squarks prefer to decay to winos/binos (not higgsinos), therefore maximum # Higgses when:

$$M_{\tilde{Q}} > M_2, M_1 > \mu$$

Boosted Higgs in the MSSM...

when the scale of SUSY-breaking is light (gmsb), gravitino is the LSP



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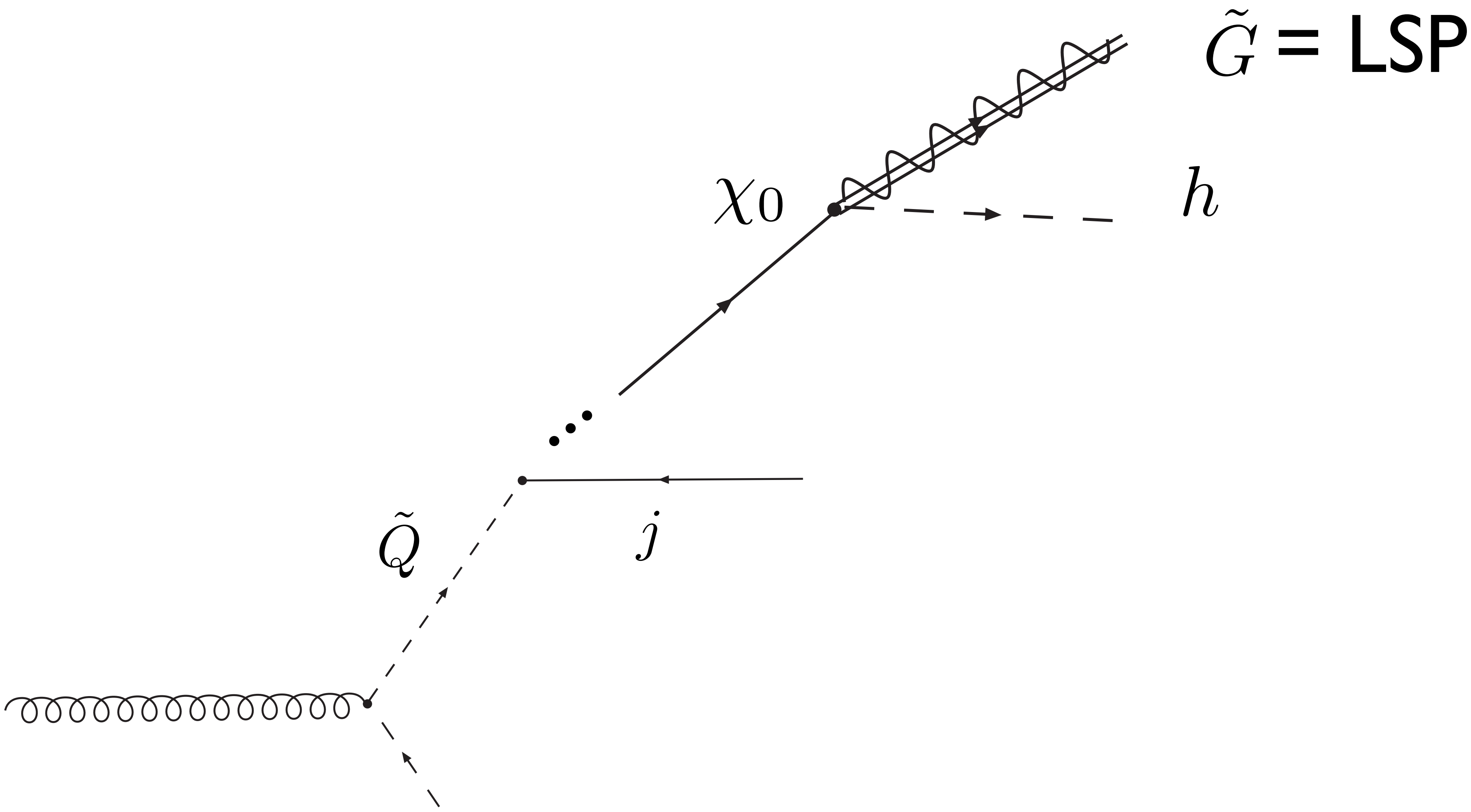

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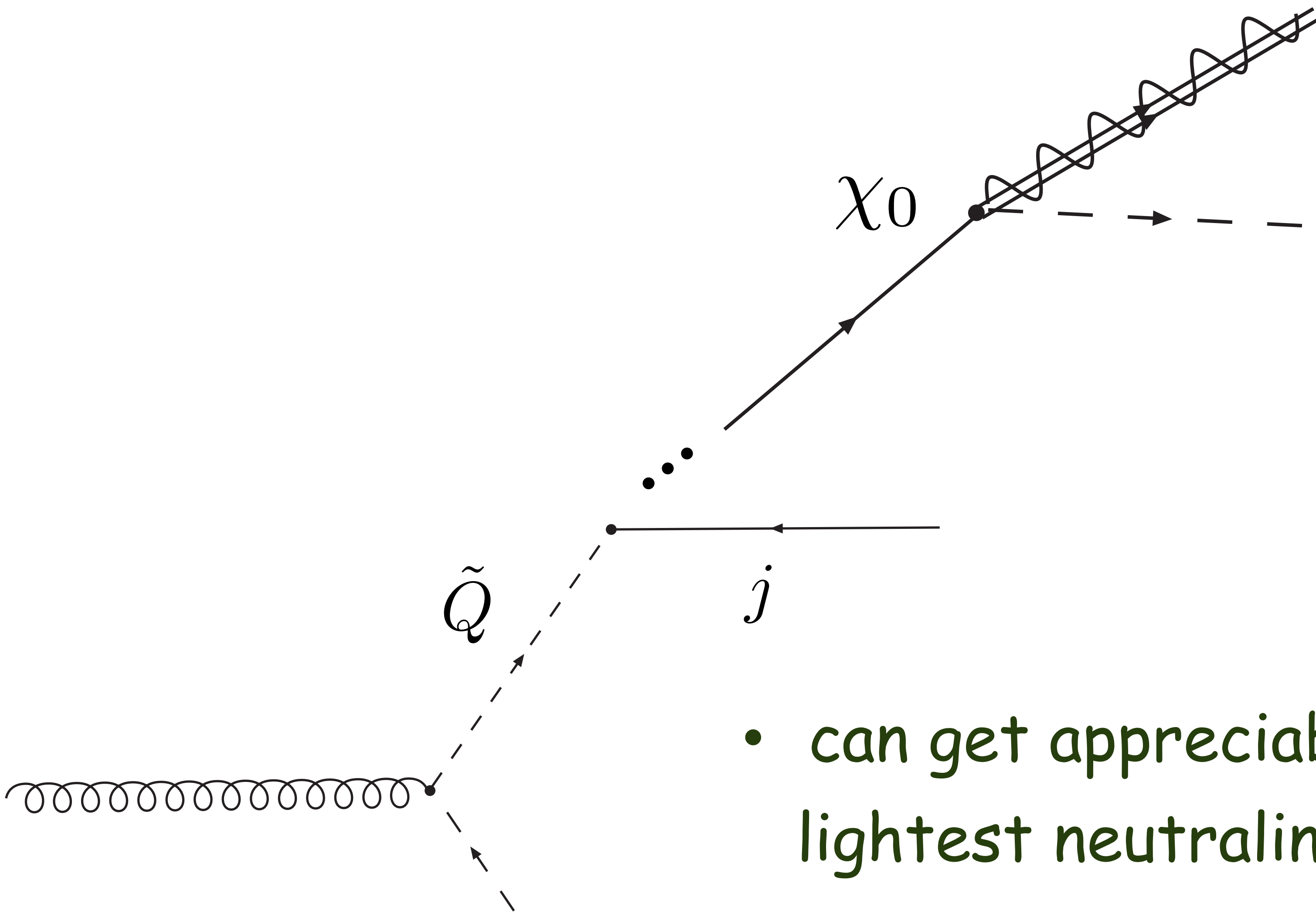


$$\chi_0 \to \gamma \,/\, Z \,/ h$$

depending on $M_1, M_2, \mu, \tan\beta$

- can get appreciable BR to Higgses when the lightest neutralino is primarily Higgsino

$$|\mu| \ll M_1, M_2$$

(Matchev, Thomas '99
Meade, Reece, Shih '09)

- Mixed decay mode $\chi_0\chi_0 \to h + \gamma + \not{E}_T + X$

is especially clean

Boosted Higgs in the MSSM...

- MSSM Higgs has to be light $m_h \lesssim 130\ \mathrm{GeV}$, decays dominantly to $b\bar{b}$
- All events have $\not{E}_T$

makes SUSY cascades ideal for Higgs hunting

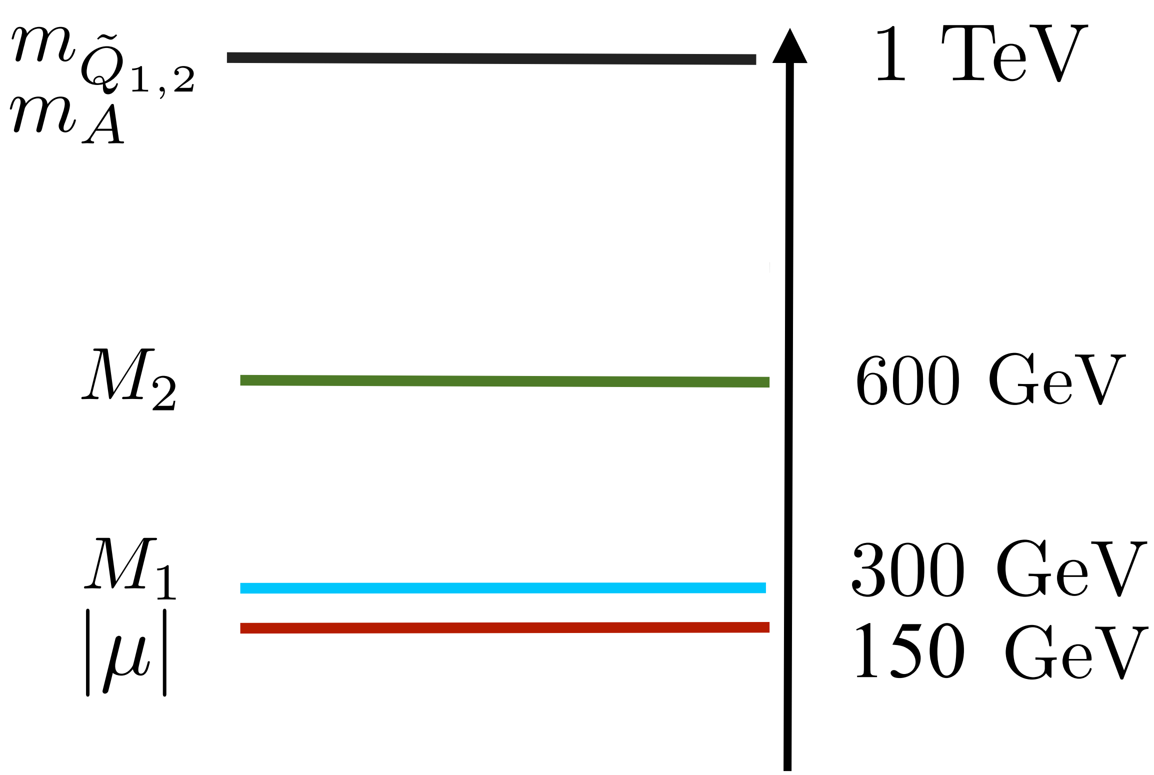
- mass hierarchy requirements are mild

BUT, don't get Higgses in cascades from mSUGRA
(so, rarely studied)

universal BC + EWSB $\longrightarrow$ large μ term $\longrightarrow$ no H in cascades

Neutralino LSP Results: #1

MET > 300 GeV, H_T > 1 TeV, 3+ jets,
no lepton, + 1 “tagged” Higgs



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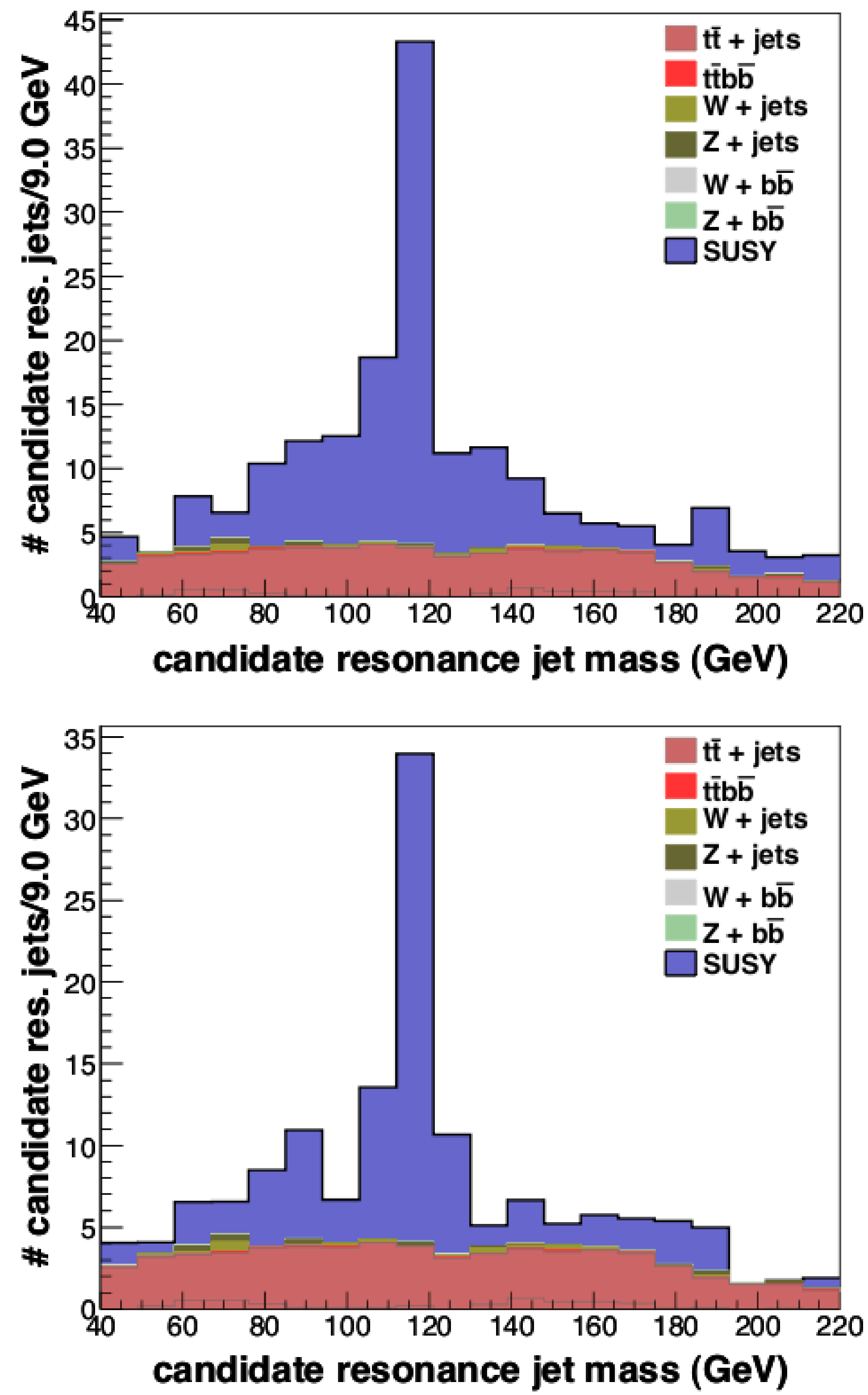

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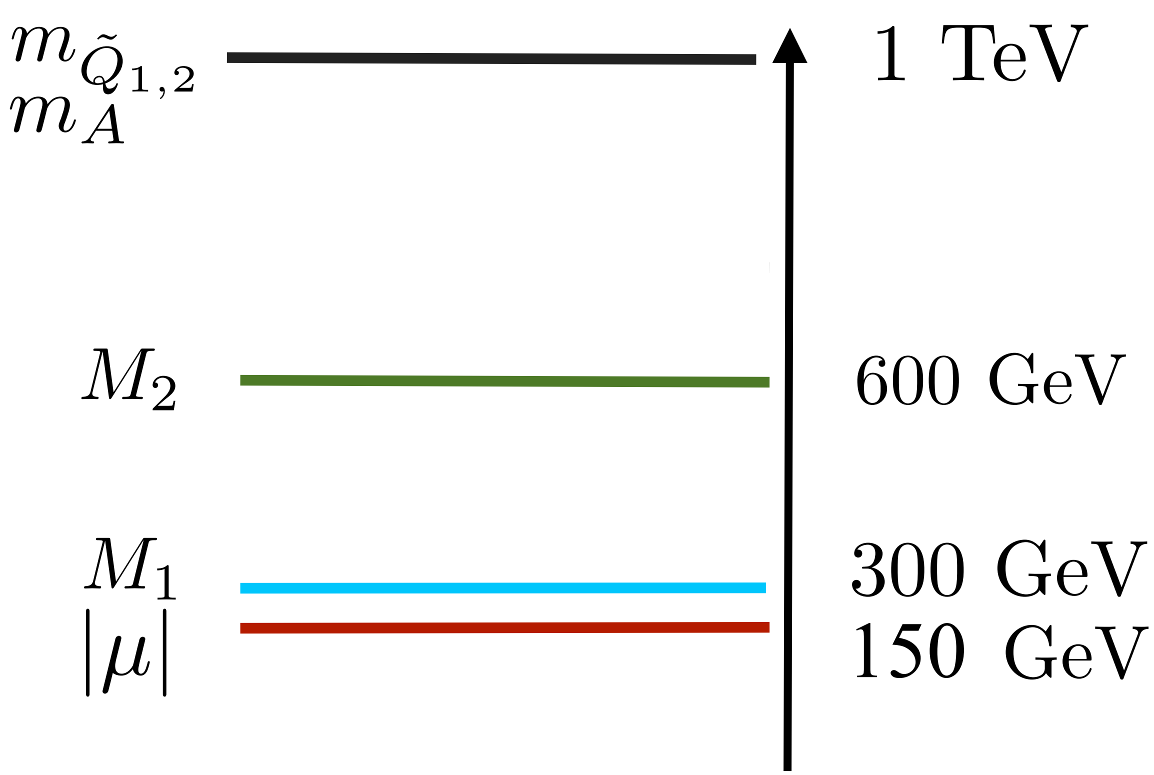

$$BR(\tilde{u}_L, \tilde{d}_L \to h + X) \sim 23\%$$
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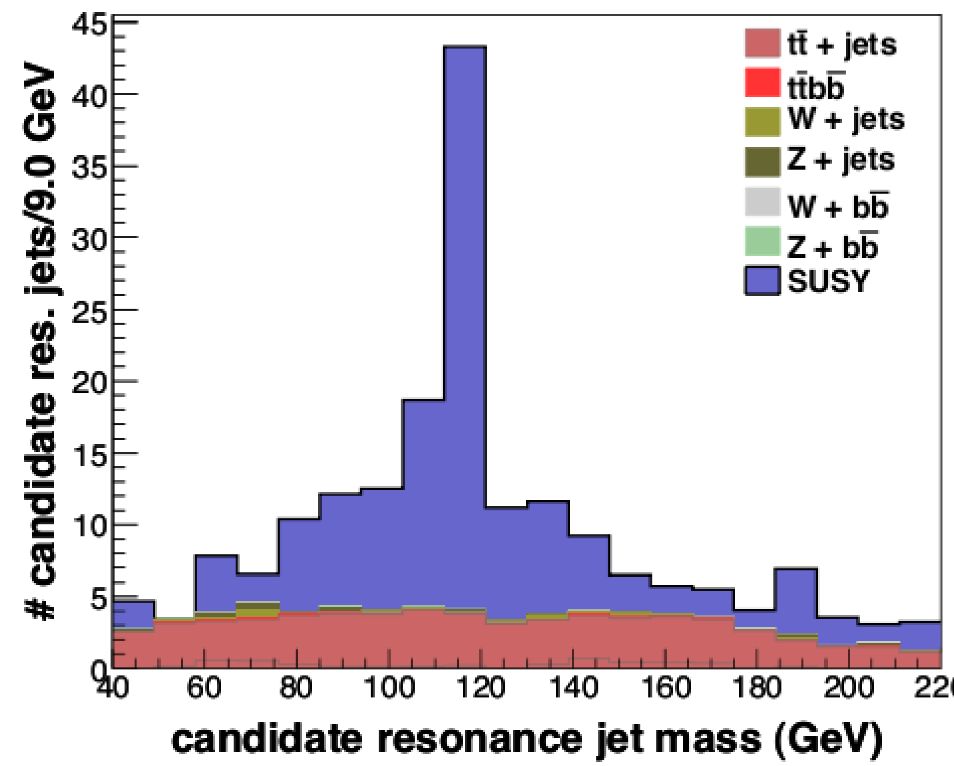

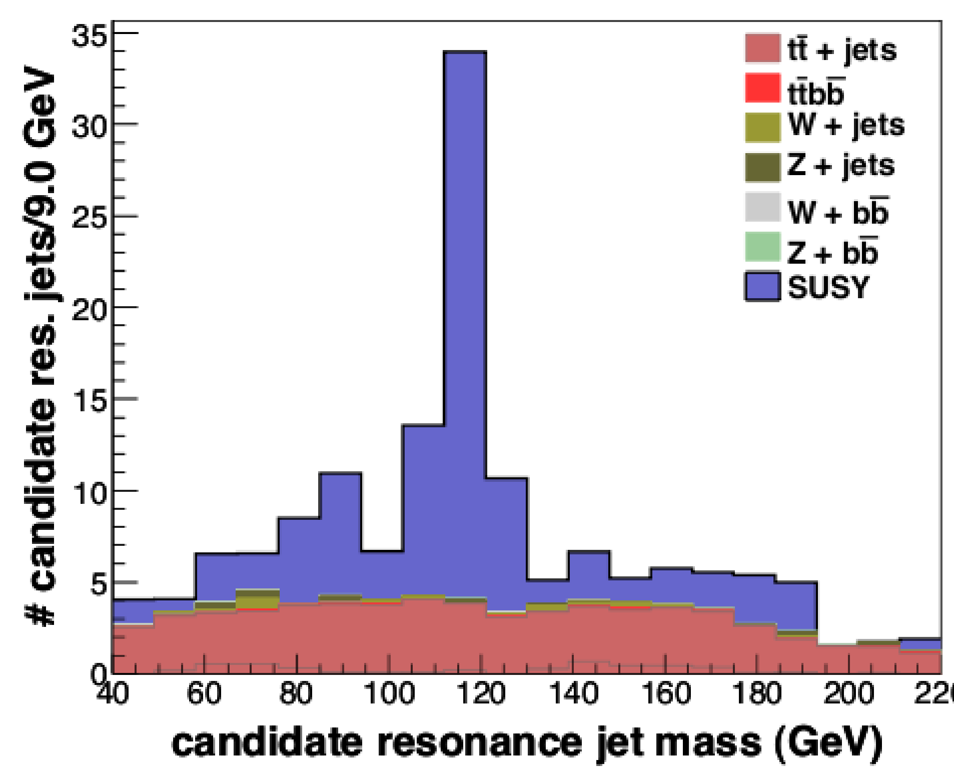

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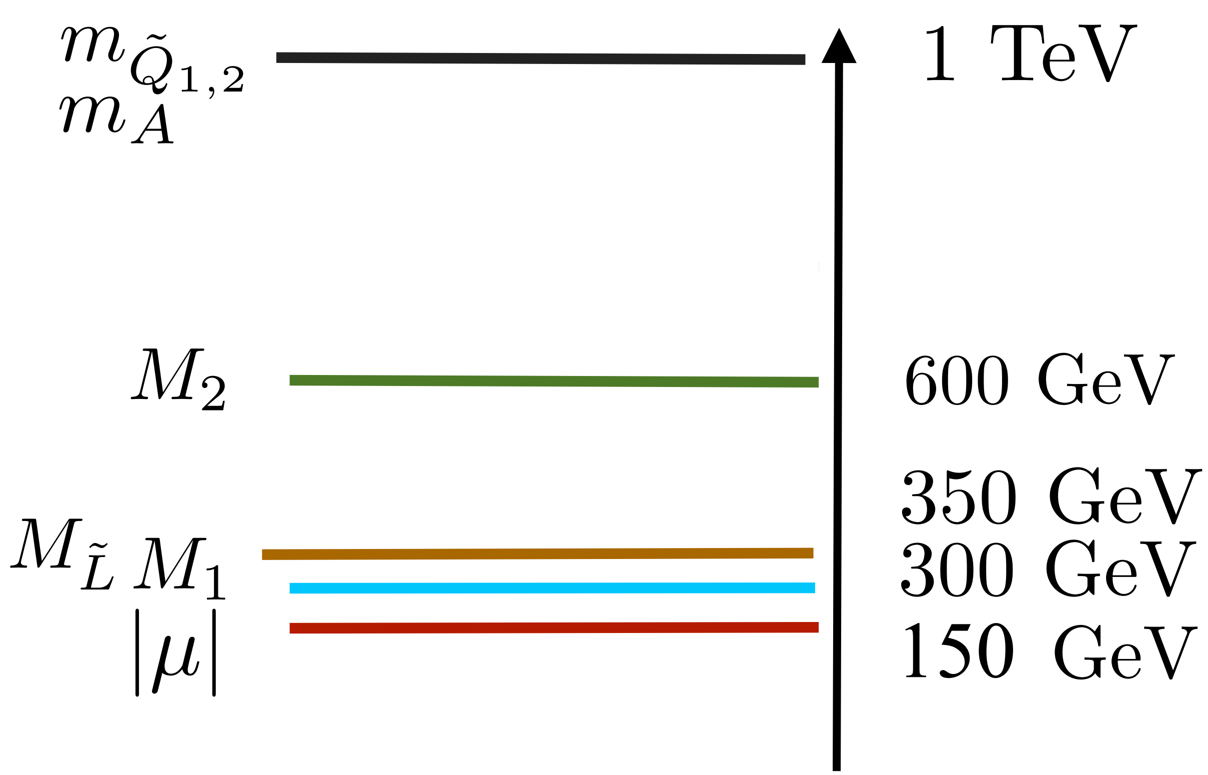

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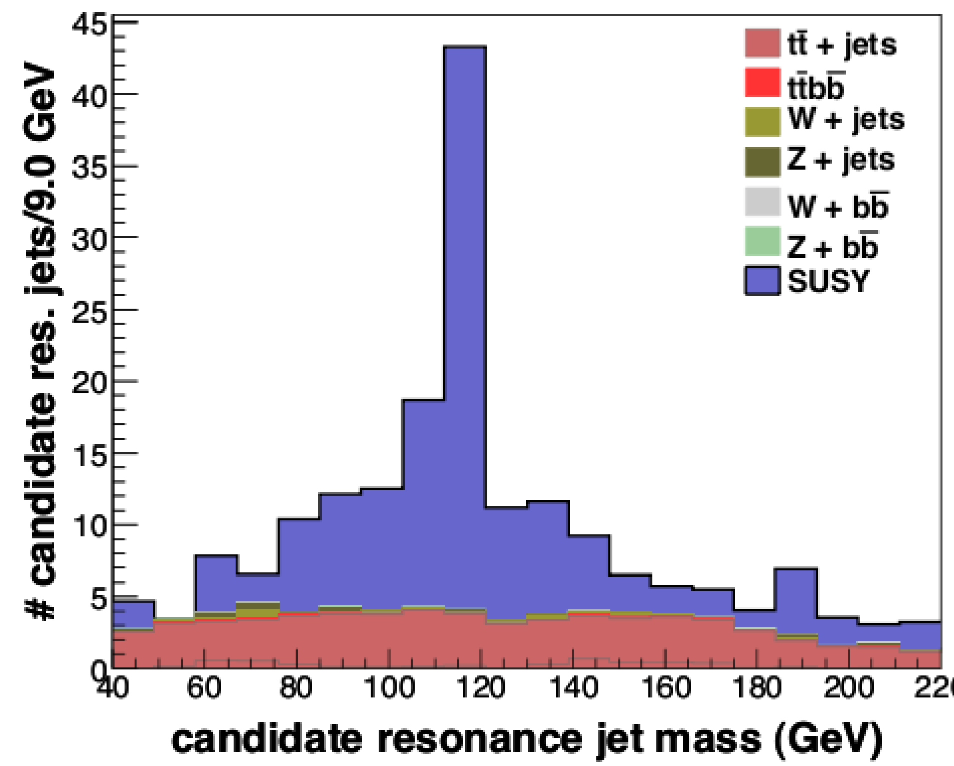
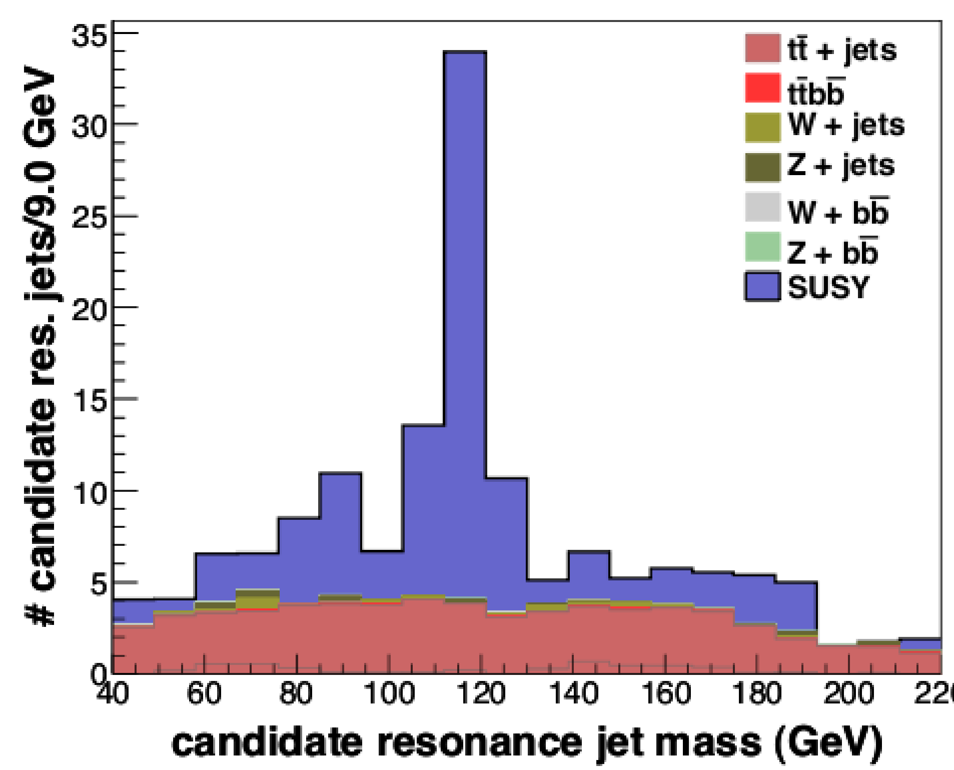
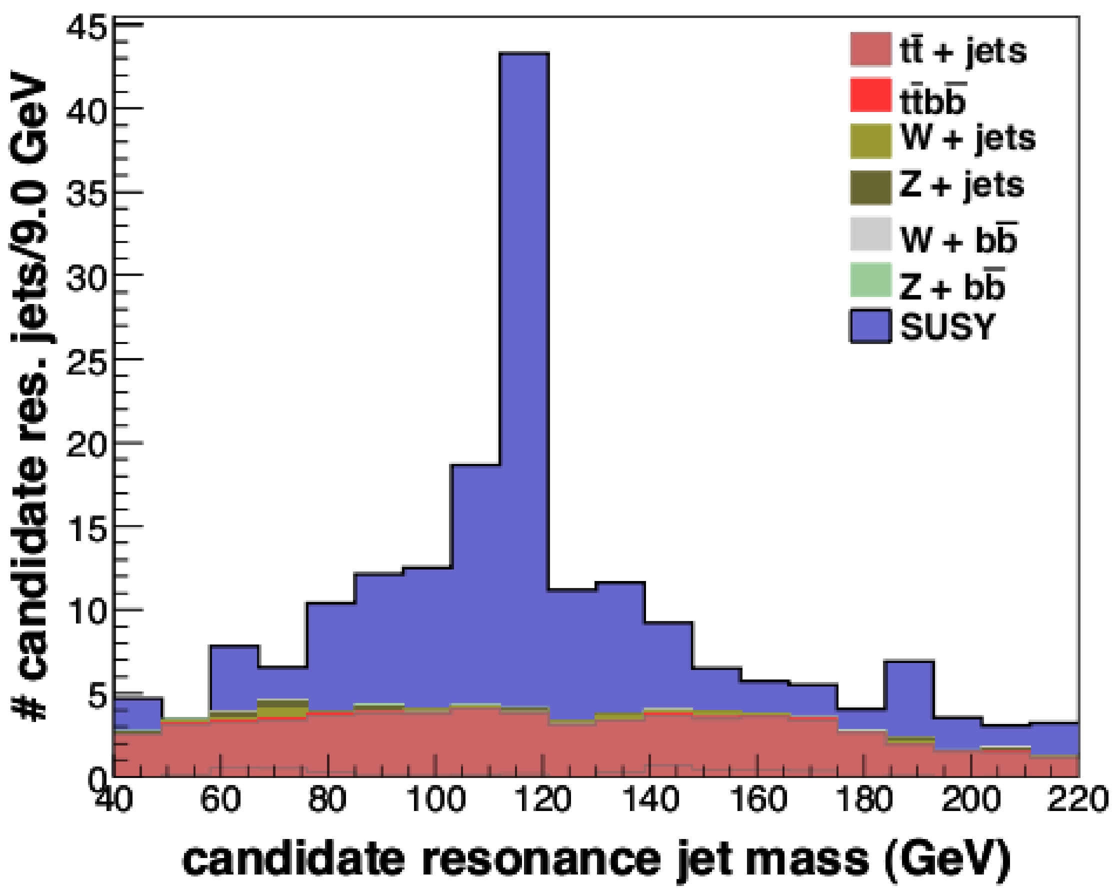


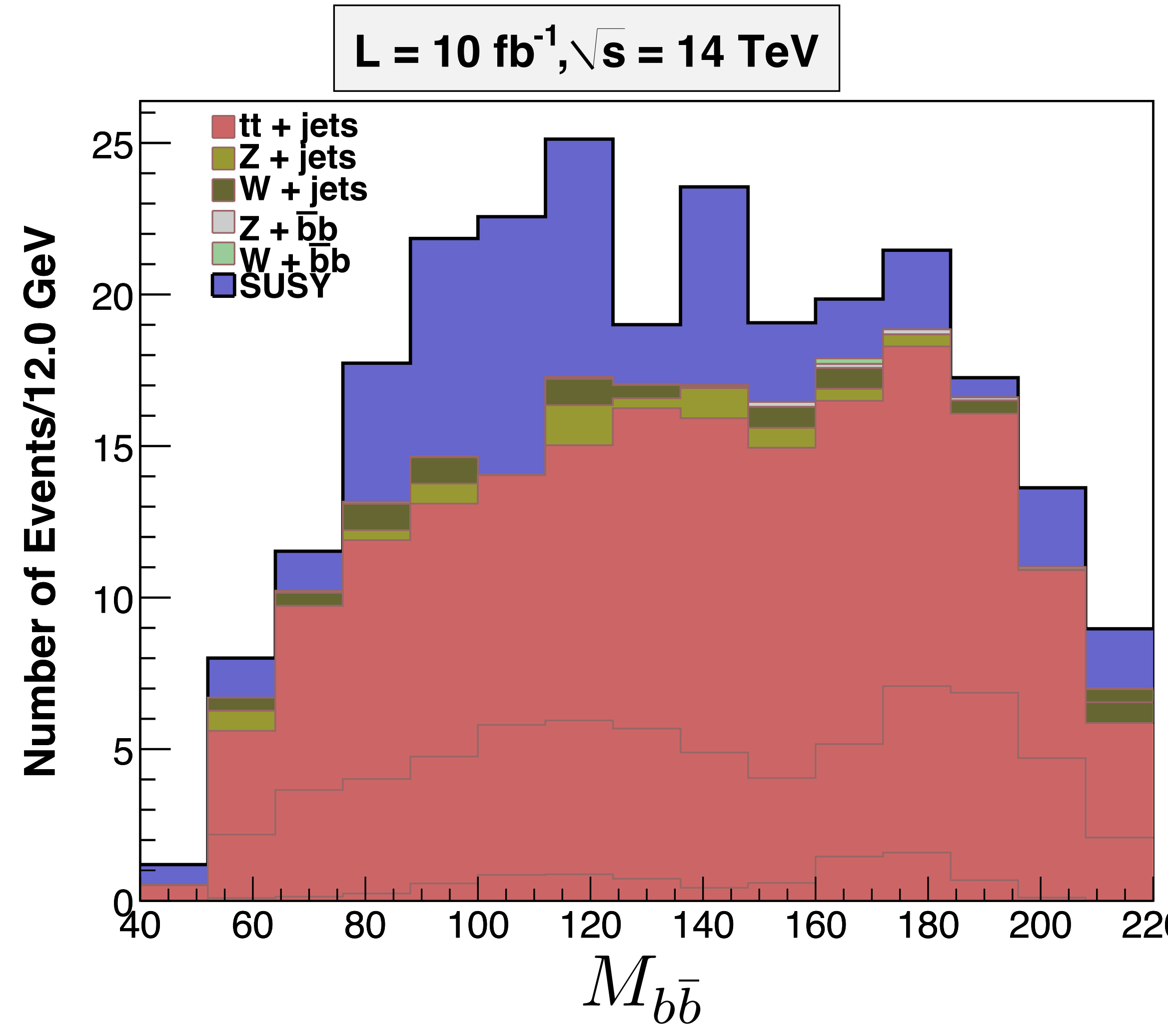


"What good is that fancy substructure?"

Comparison*: with substructure analysis vs. with PGS



$$H_T > 1 \text{ TeV}, \not{E}_T > 300 \text{ GeV}$$
$$3^+ \text{ high-}p_T \text{ jets, no leptons}$$
$$1 \text{ candidate Higgs}$$

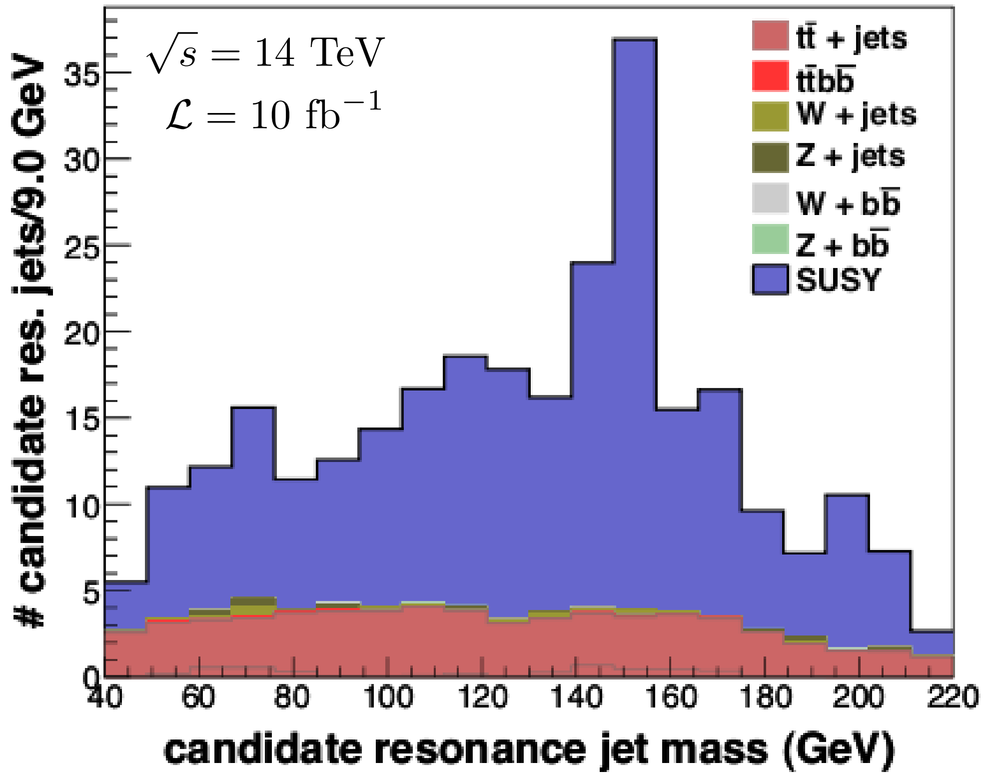


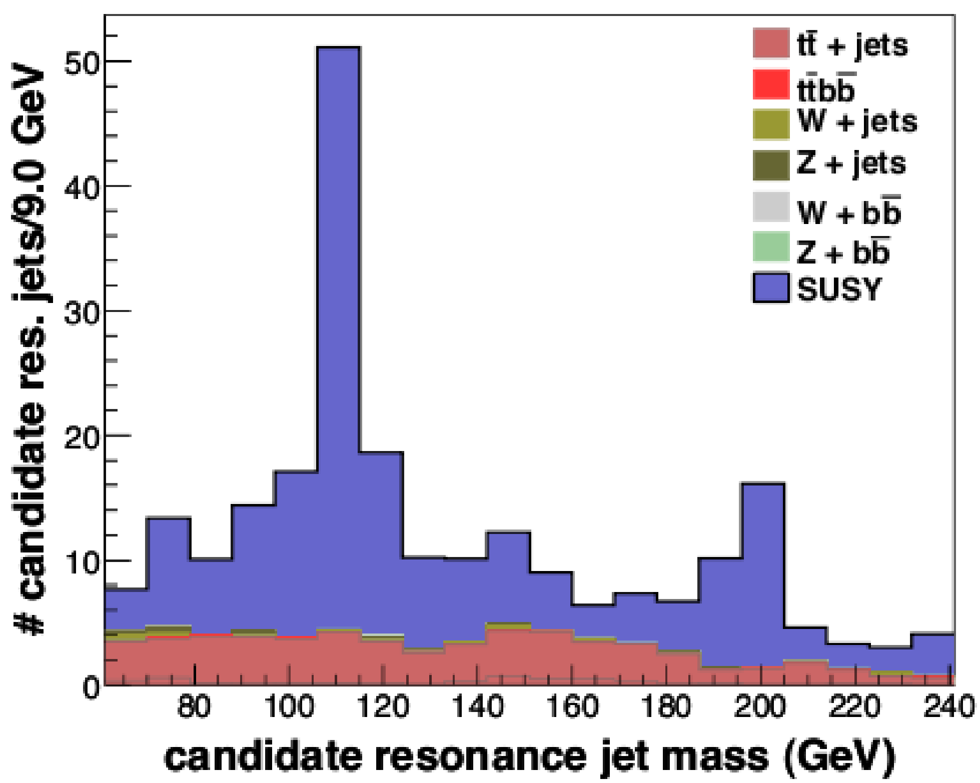
$$H_T > 1 \text{ TeV}, \not{E}_T > 300 \text{ GeV}$$
$$4^+ \text{ high} - p_T \text{ jets, no leptons}$$
$$2^+ \text{ b-tags}$$

***not totally fair**

Neutralino LSP Results: #2

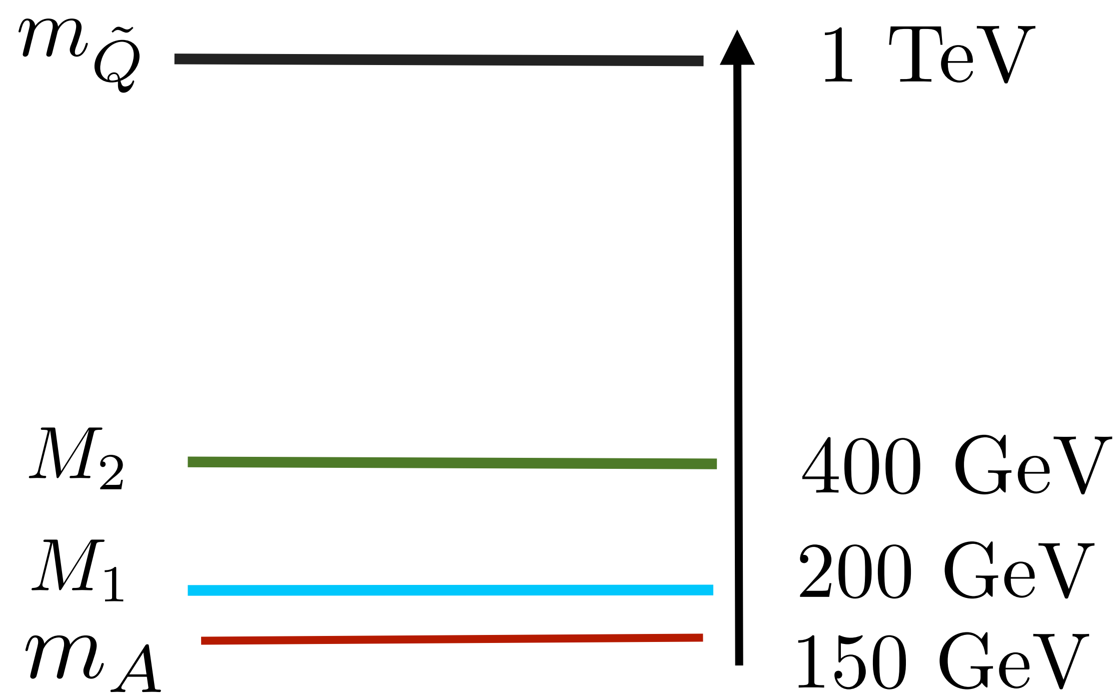
$\mu = -150\ \text{GeV},\ \tan\beta = 6.5$





$\mu = 200\ \text{GeV},\ \tan\beta = 5$

technique holds up at low m_A and $\tan\beta$, where traditional approaches have the most trouble



Can even discover heavier A,H states!

Higgses from Top-partners

In MSSM Higgs searches, the final state always contained two BSM particles (LSPs) -> an automatic handle for suppressing SM background (MET)

BUT, new physics may not have such a distinct feature

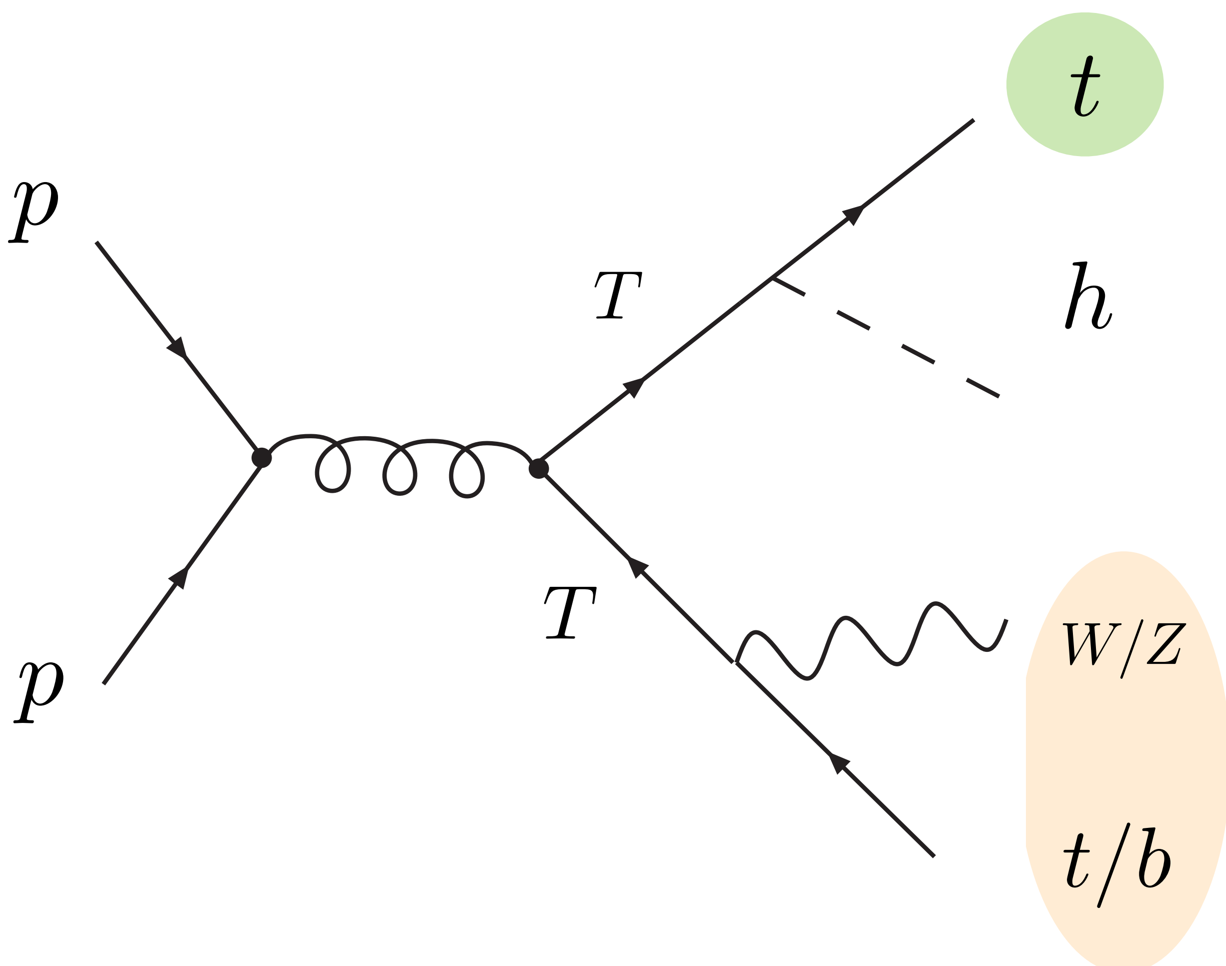
Can we still use BSM-Higgs interactions + substructure to assist Higgs discovery?

To study this, consider a minimal extension of the SM by a new vector-like quark T

$$T = (T_L, T_R) \;\; (3,1)_{2/3}$$

same Q# as t_R

Higgses from Top-partners



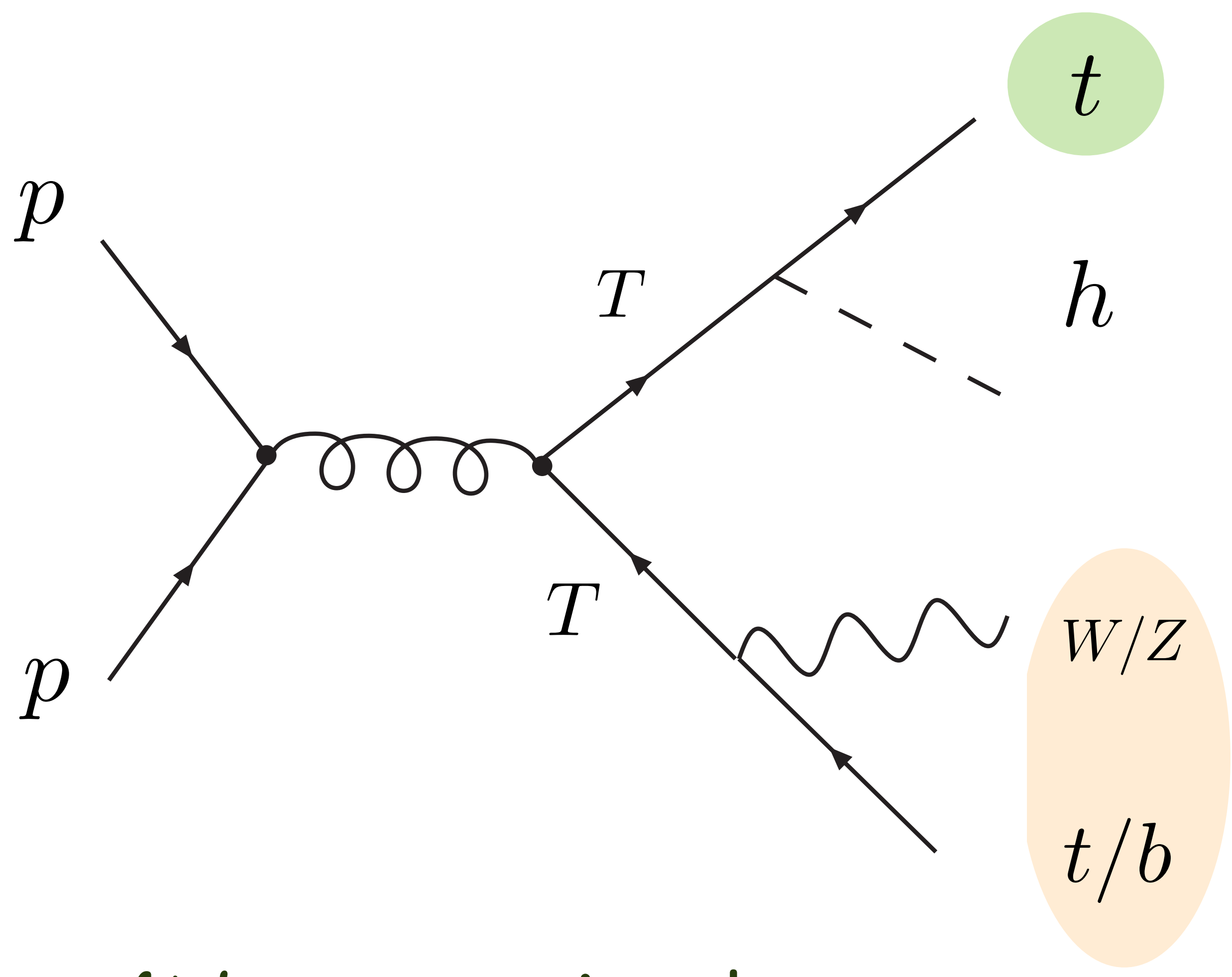
always one top quark

short cascade:
Higgs $p_T \sim M_T/2$
(vs. $\sim M_T/4$ for MSSM)

+ additional gauge boson/top

4^+ bs, many jets!

Higgses from Top-partners



always one top quark

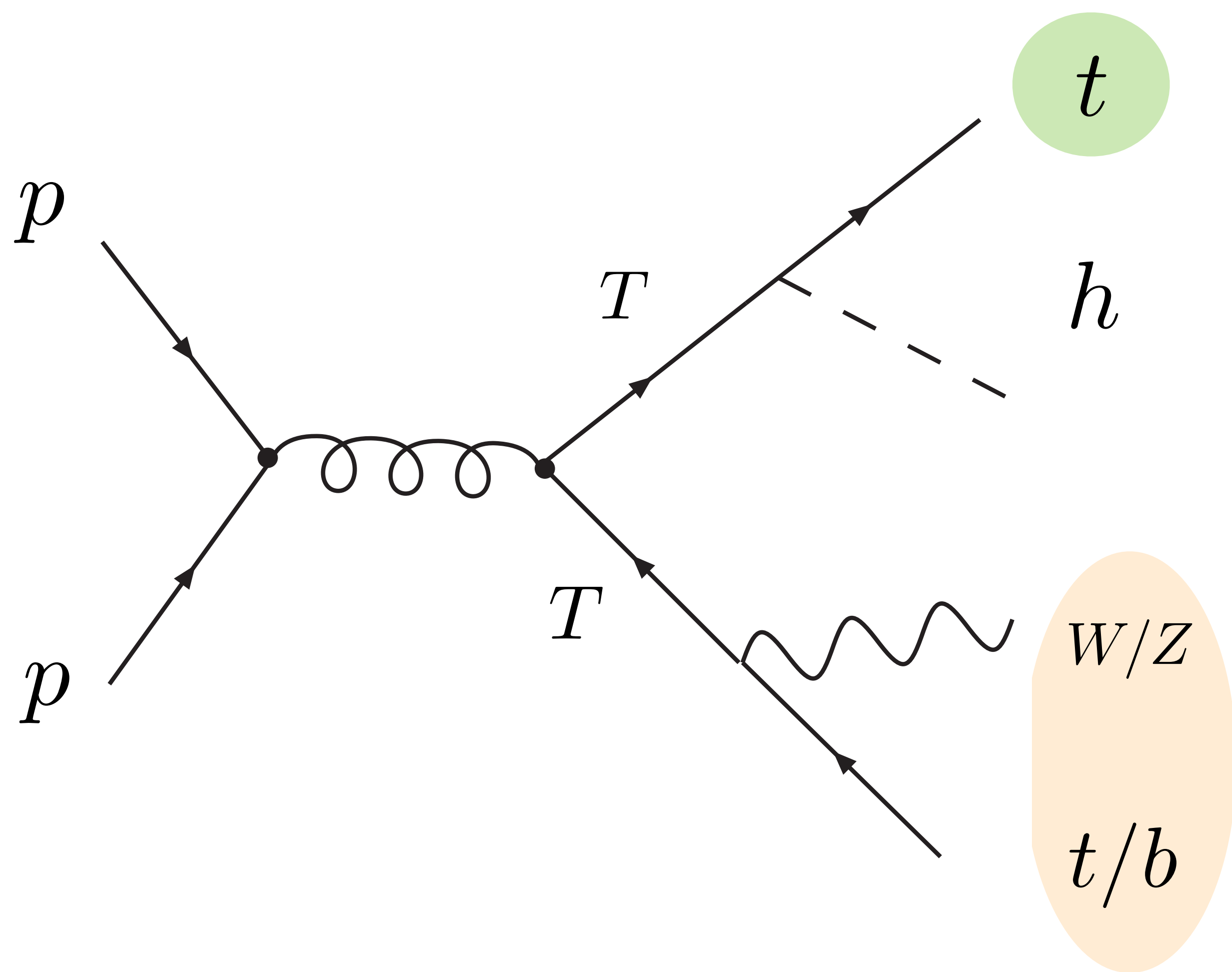
short cascade:
Higgs $p_T \sim M_T/2$
(vs. $\sim M_T/4$ for MSSM)

+ additional gauge boson/top

4^+ bs, many jets!

final state characterized by multiple, highly boosted resonances

Higgses from Top-partners



always one top quark

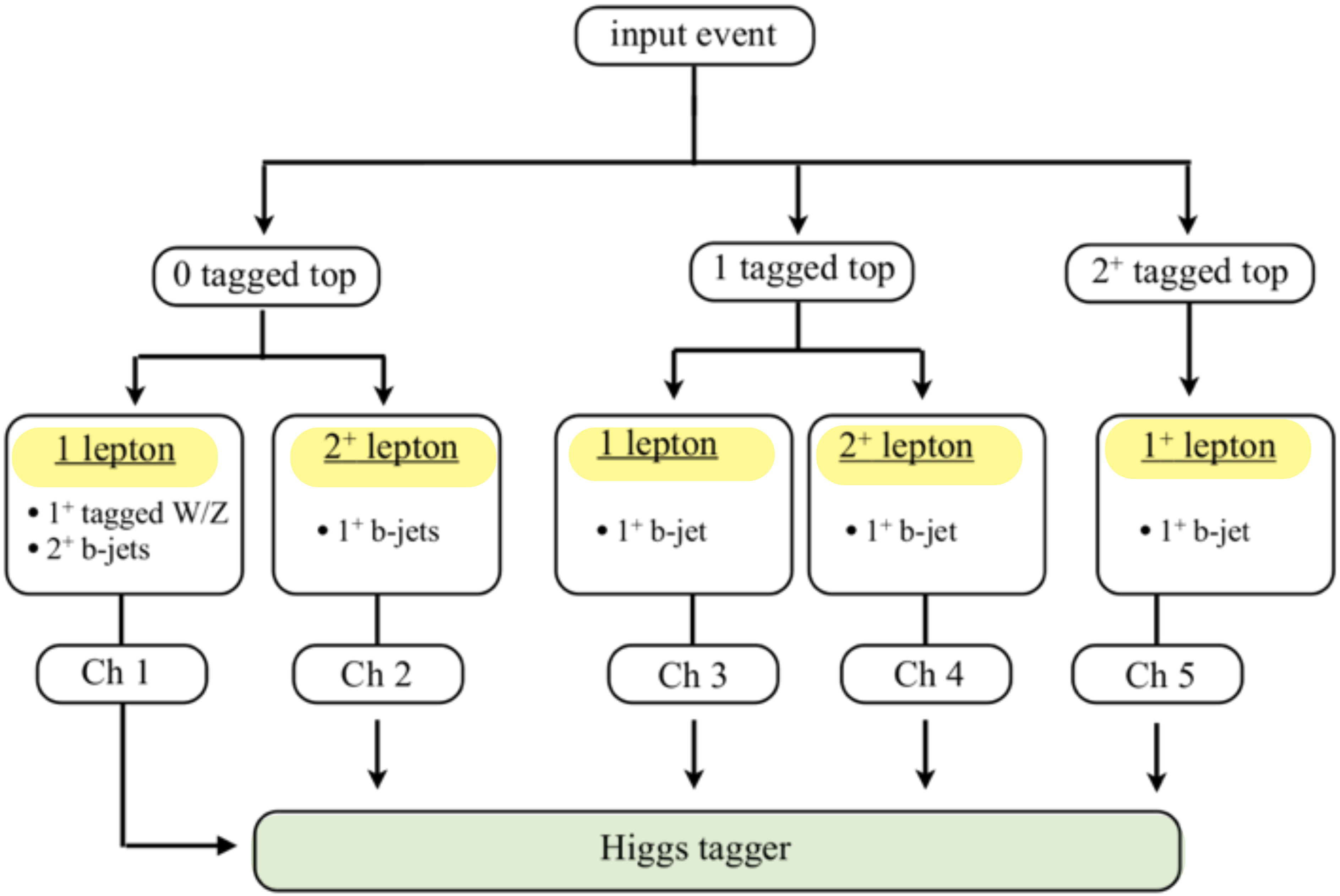
short cascade:
Higgs $p_T \sim M_T/2$
(vs. $\sim M_T/4$ for MSSM)

+ additional gauge boson/top

4^+ bs, many jets!

require multiple 'tags' (Higgs + top, Higgs + W, etc.) to suppress SM background, ease combinatorics

Higgses from Top-partners



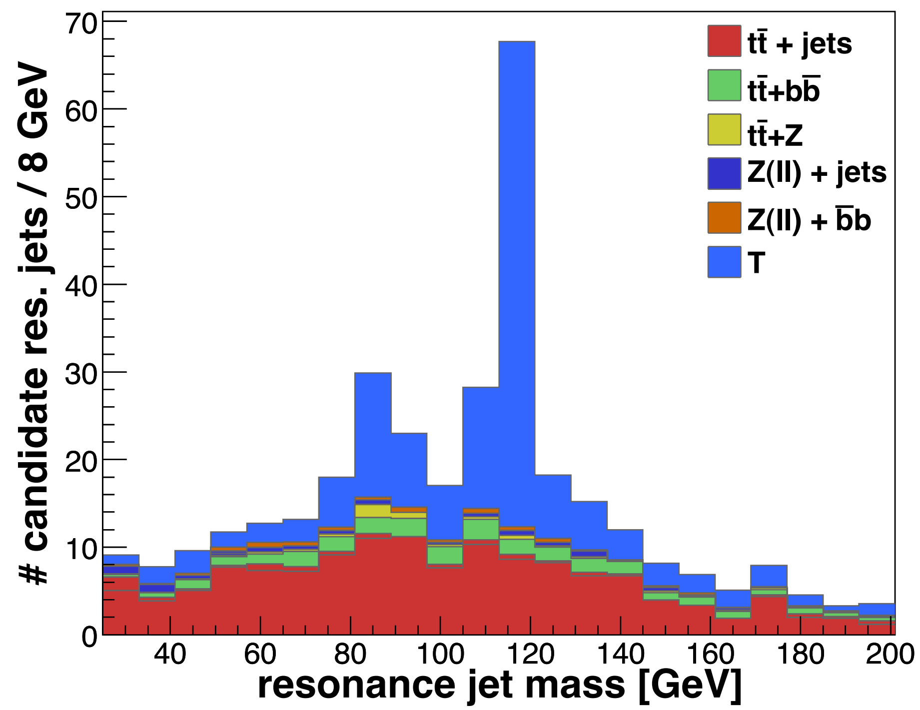
Different analysis pathways for different T masses

Higgses from Top-partners: results

M_T ~ 500-600 GeV, all channels work well

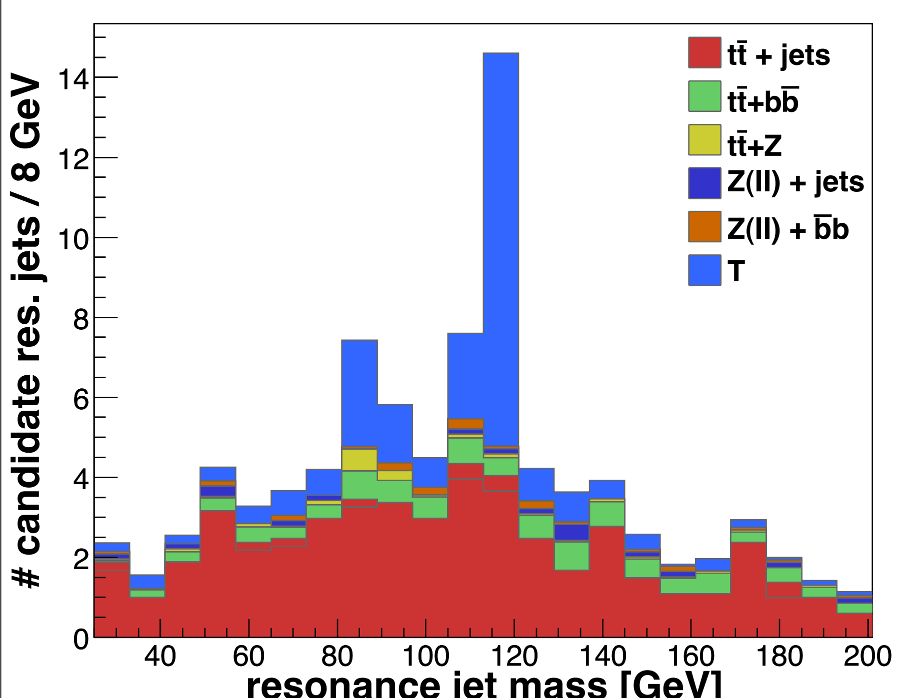
(plots: $\sqrt{s}$ = 14 TeV, 10 fb^{-1})

$$M_T = 600 \text{ GeV}$$



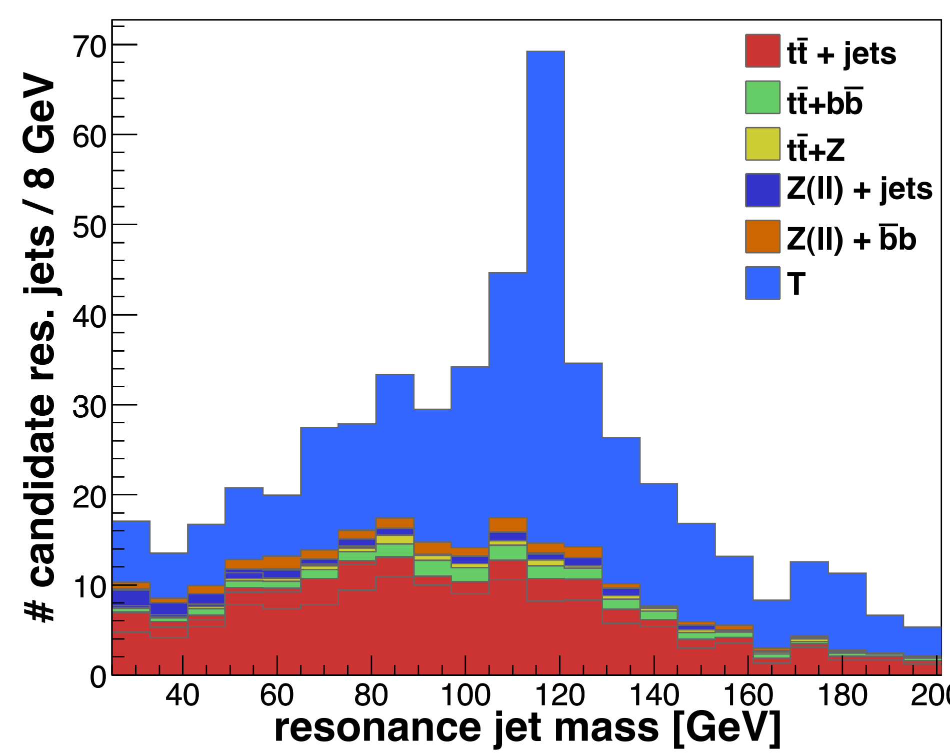
lighter M_T: higher rate, but less boost -> multi-lepton channels work better

$$M_T = 800 \text{ GeV}$$



opposite is true for higher M_T: channels w/ multiple boosted resonances work best

$$M_T = 400 \text{ GeV}$$



Conclusions

BSM particles are often heavy, interact with Higgs
-> decay of BSM stuff to Higgs is a great source of boosted Higgses

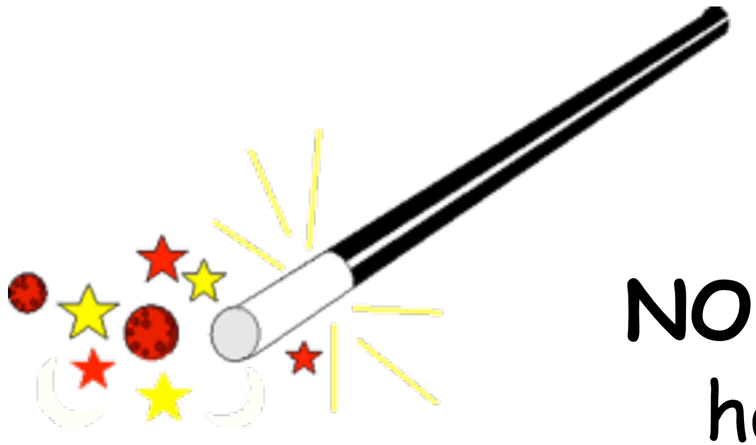
inclusive BSM signal + conventional cuts + BDRS substructure --> fantastic (light) Higgs signals, easily as significant (or more so!) than $h \to \gamma\gamma$, $h \to \tau\tau$

ex.)

- single BDRS-tagged object -- MSSM
- multi-tagged objects, tagged tops + h/W/Z -- Top-partner

plenty of room for more optimization, plenty of other tools to try out

EXTRAS



Substructure = Magic?

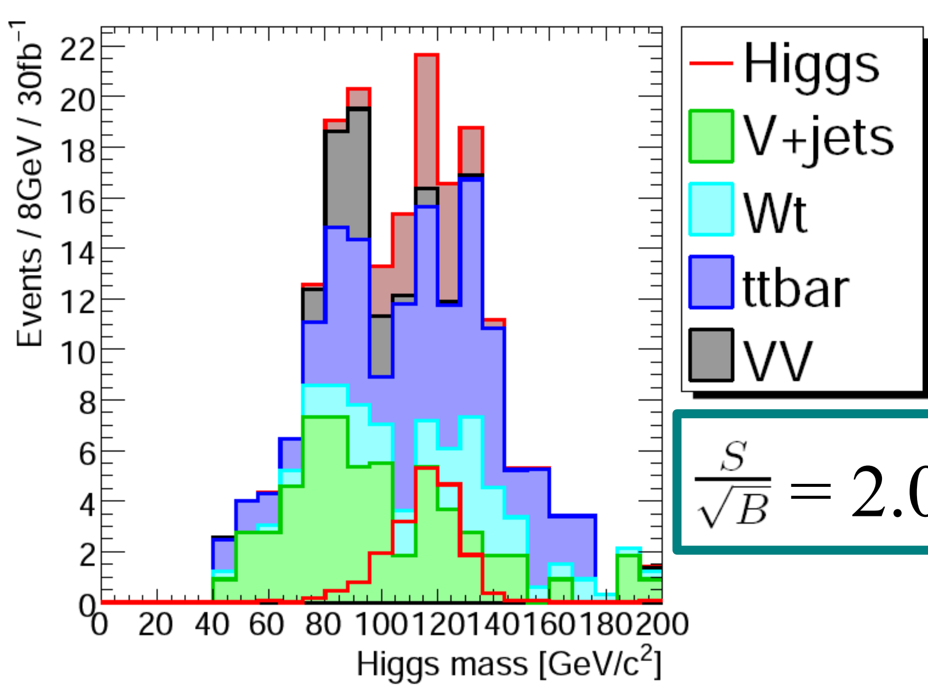
NO, but packages together several effective handles which separate decay of high-pT color-singlet resonance from QCD

these handles can be mimicked with fixed-R (more conventional) analysis, to some extent

fixed R, + 'subjet inspired' cuts vs. subjet based

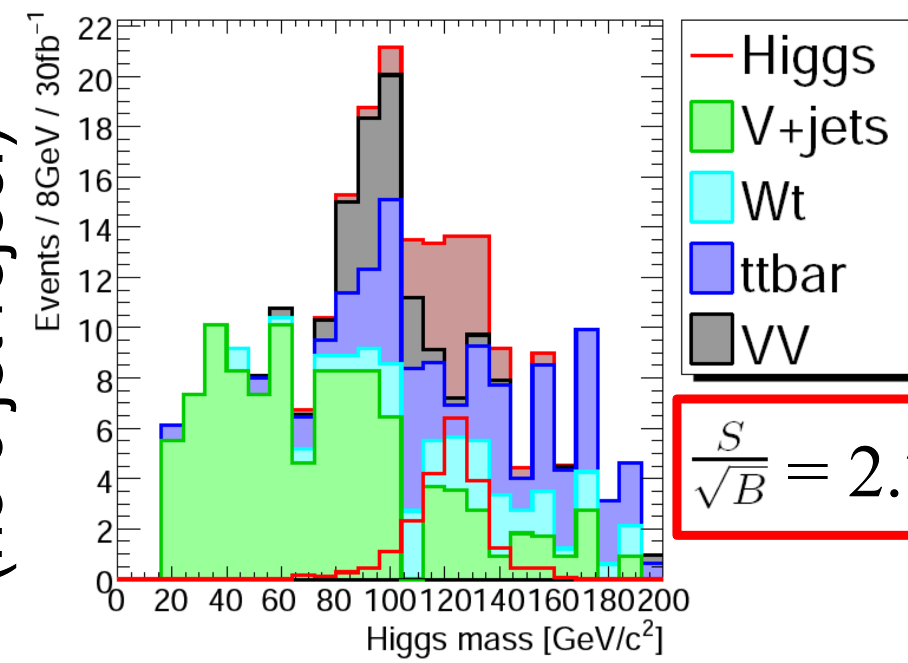
$L=30\ fb^{-1}$

Jet based R=0.4



$$\frac{S}{\sqrt{B}} = 2.0$$

Subjet based (no c-jet rejec.)



$$\frac{S}{\sqrt{B}} = 2.7$$

(from G. Piacquadio, Oregon Jet Workshop 2011)

Results: Details

Background: ALPGEN → PYTHIA6.4

Signal: SUSPECT2 → PYTHIA6.4

underlying event: ATLAS tune

- All final-state hadrons grouped into cells of size $(\Delta\eta \times \Delta\phi) = (0.1 \times 0.1)$
- Each cell is rescaled to be massless

jet gymnastics performed using FastJet (hep-ph/0512210)

b-tagging: 60% efficiency, 2% fake rate

jet-photon fake rate: $.1\%$

MSSM + boosted Higgses

Branching ratios and boosted fraction: neutralino LSP

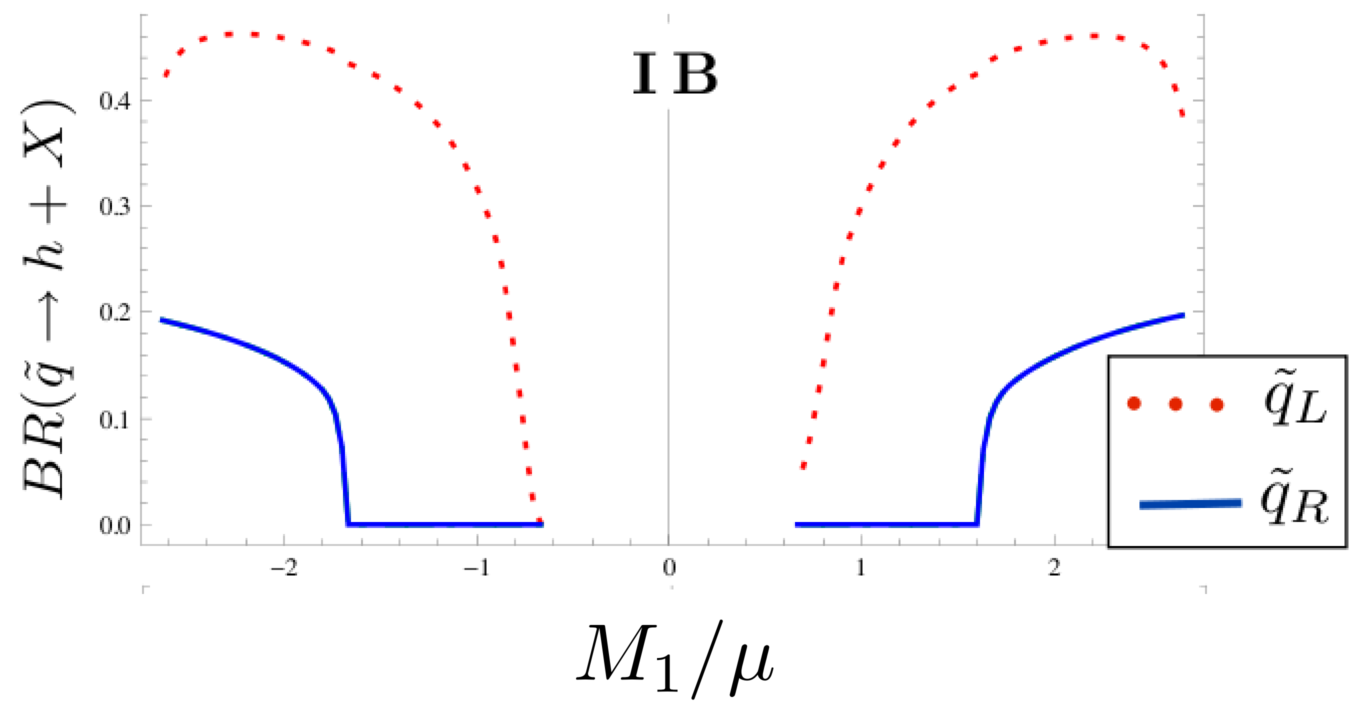
Ex.) $M_{\tilde{Q}} = 1$ TeV

$\tan\beta = 10$

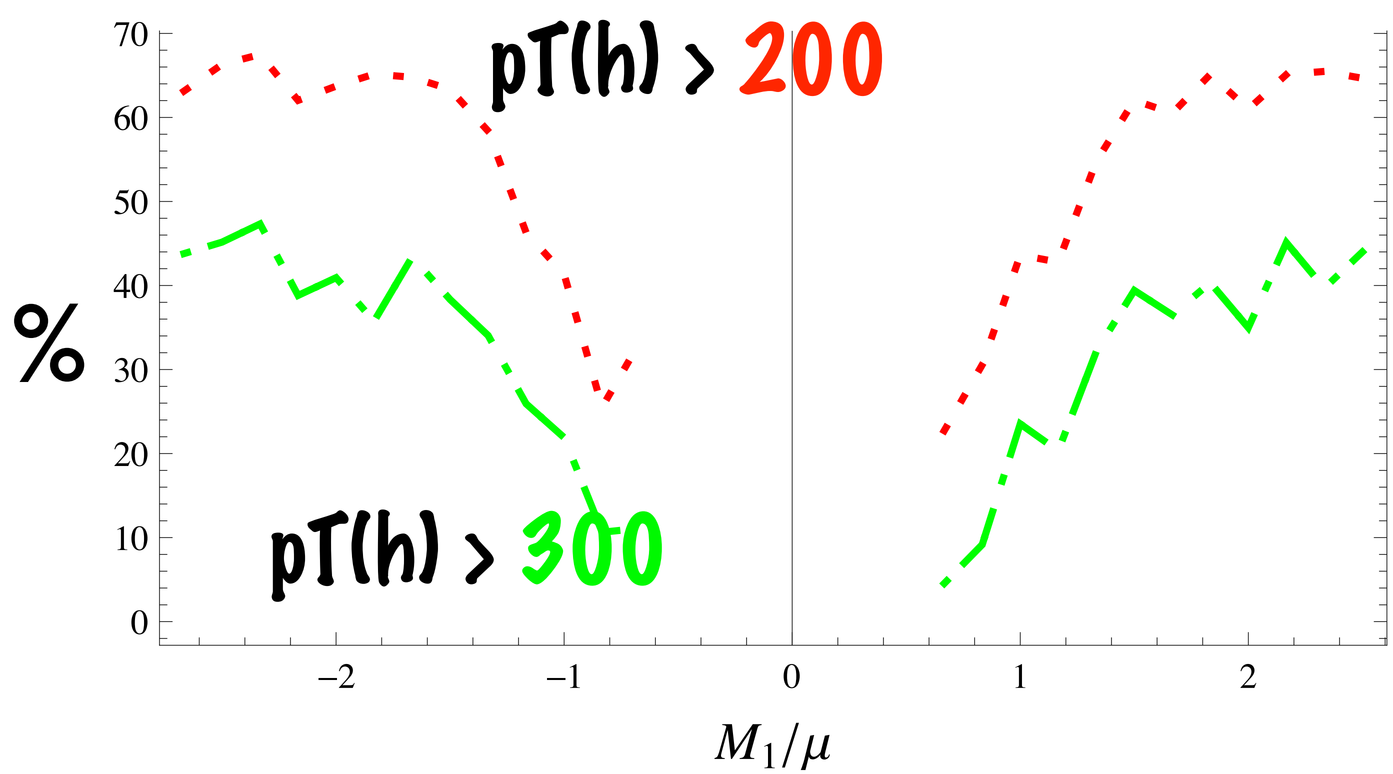
$\mu = 150$ GeV

$M_{\tilde{L}} = 1$ TeV

$M_2 = 2M_1, M_3 = 7M_1$



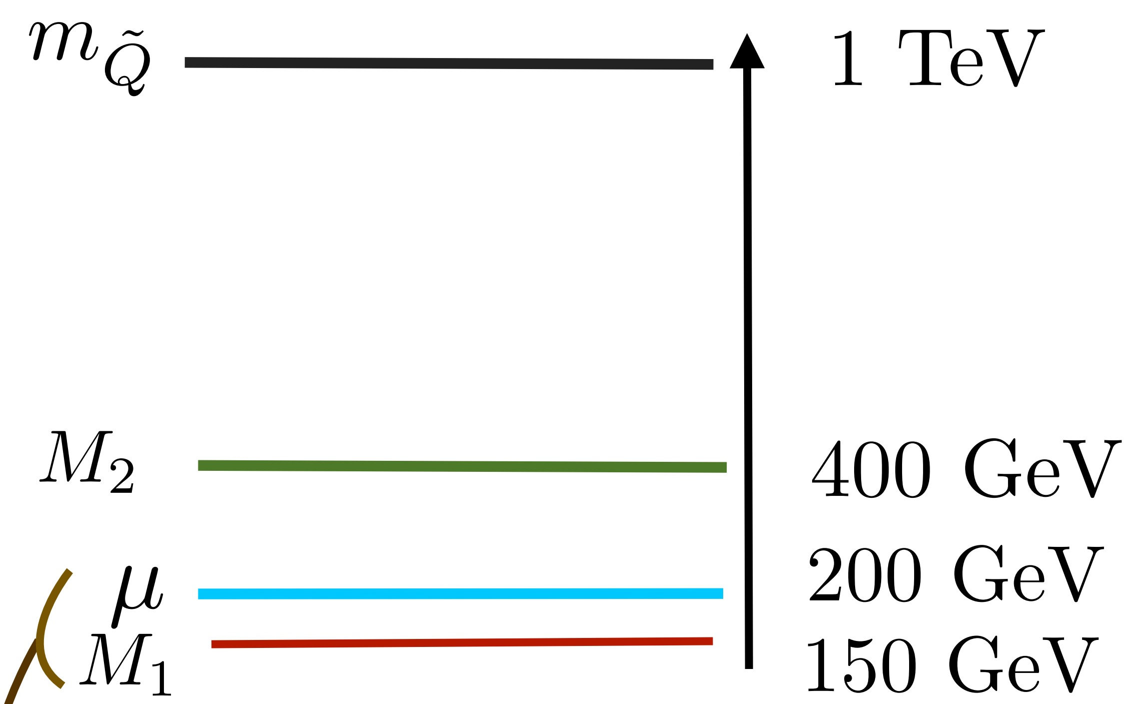
Boosted Fraction

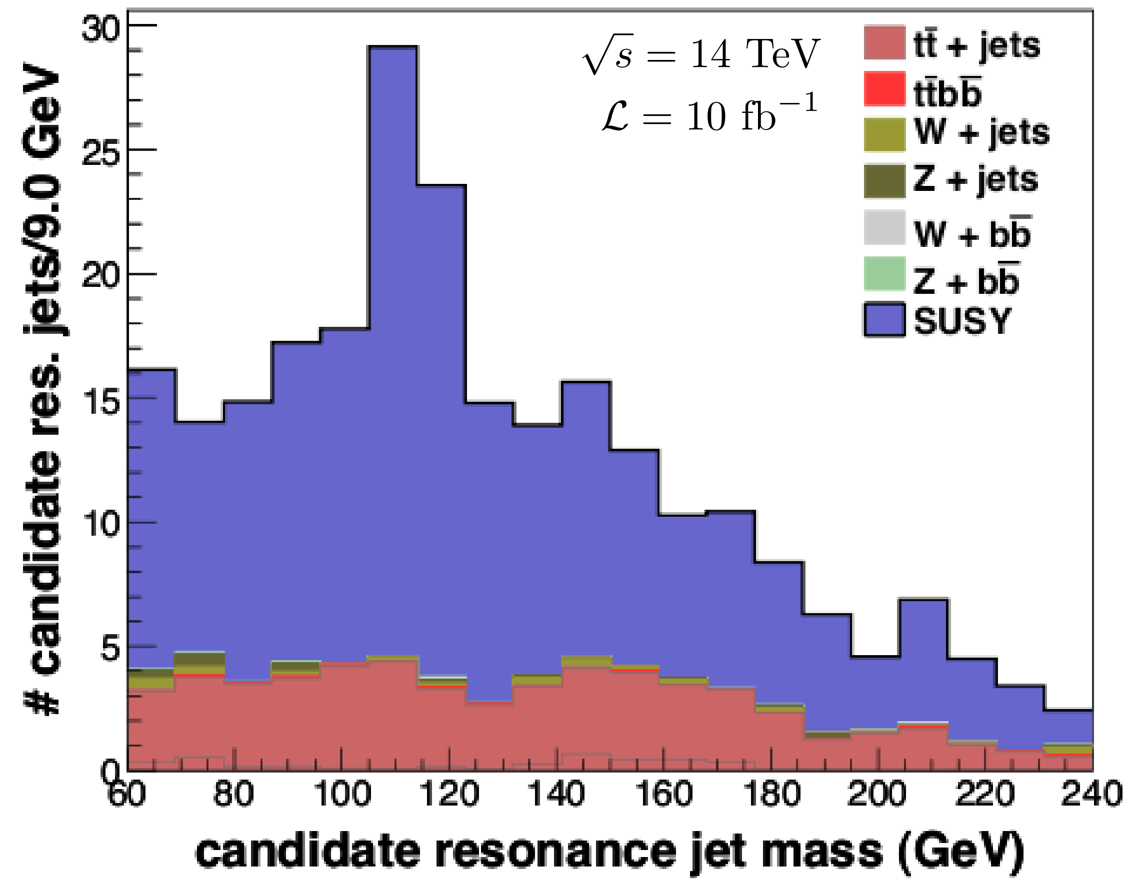


"But I really liked SUSY Dark Matter..."

Though we typically have too little DM

permitting $M_1 \lesssim \mu$, we can get consistent Ω_{DM} without losing all our Higgses





$M_1 \lesssim \mu$ shuts off bino -> Higgsino decays

shuts off RH squark to Higgs cascades, reducing the signal rate